History matching sensitivity investigations and forecasting for low matrix porosity, permeability and highly fractured carbonate reservoir to optimize oil production in Kurdistan Region

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Declaration

I hereby declare that I completed this work without any improper help from a third party and without using any aids other than those cited. All ideas derived directly or indirectly from other sources are identified as such.

In the selection and in the use of materials and in the writing of the manuscript I received support from the following persons:

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Persons other than those above did not contribute to the writing of this dissertation. I did not seek the help of a professional doctorate-consultant. Only persons identified as having done so received any financial payment from me for any work done for me.

This dissertation has not previously been submitted to another examination authority in the same or similar form in Germany or abroad.

Sarko H. Hakim

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Dedicated to

The soul of my father … Hussen

My mother …. Gelas

My brother …. Twana and his wife …. Shox

My nephew …. Sahand and My niece …. Sanar

Abstract

Reservoir simulation is very important tool in petroleum industry. It leads to better understanding of the hydrocarbon reservoir's behavior and its future performance. During the simulation workflow a three dimensional geological model for the reservoir is generated and calibrated via history matching process in which the production data is needed mainly. The calibrated model shall be reliable for predicting the future performance of the reservoir. This is essential for development planning and proper management of the oil field in order to increase the production rate and the recovery. Many carbonate reservoirs with low matrix porosity, low matrix permeability and highly fractured have been managed improperly due to the excessive production rate which led to faster reservoir depletion and lower ultimate recovery. This analysis is very important to avoid such situation especially for complicated reservoirs. Taq Taq oil field in Kurdistan region – Iraq has been selected as an investigation case.

Petrel software has been used to build the three dimensional geological model. The required data was provided by the Ministry of Natural Resources of the Kurdistan regional government – Iraq. Eclipse 100 (Black Oil) has been used for running the simulation. Taq Taq oil field consists of two main pay zones. The first one is about 600 meters deep and it has not been covered in this research as it contains heavy oil. The second pay zone is about 2000 meters deep and consists of low matrix porosity, low matrix permeability and highly fractured carbonate rock which contains light oil and it is the investigation case of this research. Taq Taq oil field is in its early stages of production, hence proper field development, planning and management is important and necessary to avoid early reservoir depletion and to avoid low recovery.

The results show excellent oil rate history matching and after several attempts the matching case regarding the gas production rate has been achieved. The gas oil ratio and bubble point pressure have been manipulated to obtain the matched case. Only two history matching simulation cases are presented in this research.

The water production rate was very tiny in the observed production data as well as in the prediction cases.

After getting the matched case for both oil and gas, four prediction scenarios were carried out in order to know how the reservoir will perform with the required production conditions. Three wells have been suggested as producers and included in two prediction cases to see their effect on the recovery. The results show that the less excessive production rate can last longer than the more excessive production rate. Within the two less excessive prediction scenarios, the case with the three producers show higher recovery than the case without the three suggested producers whereas in the other two more excessive prediction cases the three producers show no effect on the recovery. The fifth prediction scenario has been carried out for the more excessive production case in which the three suggested production wells have been converted to gas injectors. The effect of the gas injection can be seen very clearly in increasing the recovery.

The procedure of this work can be applied to any reservoir in the world. The tool (software) which has been used in this research is able to simulate each well in the field which can be considered as one of the strength points for this investigation. In addition to that, the simulated cumulative oil rate (prediction cases) shows comparable and reasonable result with the actual one which has been announced by the operator company in Taq Taq oil field. The results are showing also that even for a short period of time (relatively) history matching and prediction can be run which can be considered as another strength point of this research. The oil industry in the Kurdistan region – Iraq is new and very attractive to the oil companies in the world and that is why Taq Taq oil field has been selected.

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1. Introduction

Reservoir simulation investigations are conducting mostly in sake of hydrocarbon reservoir development planning and its management optimization. Carbonate reservoir with low matrix porosity, low matrix permeability and highly fractured has important contribution to the world oil reserve despite their complexity. Many fractured reservoirs in the world are managed improperly due to the extreme production rates during the on stream and unsuitable planning which led to less ultimate recovery. Such reservoirs should be managed correctly in order to produce hydrocarbon for longer period of time and avoiding excessive production rate which lead to quick pressure decline and lastly reservoir depletion.

For instance, Yanling karstic carbonate oil reservoir in northeastern China, the excessive production rate led to rapid pressure and production drop at the very first two years of the production whereas Casablanca oil field which is also karstic carbonate reservoir in offshore Spain was controlled by manipulating the choke size whenever the water cut reached two percent and therefore Casablanca field had better ultimate recovery than Yanling field (Allan J. et al 2003).

The required recipe for obtaining good simulation and appropriate reservoir management include accurate and sufficient data which are required to build three dimensional geological model of the reservoir. Carbonate reservoir modelling is very sophisticate and dual properties (porosity and permeability) modelling should be taken into consideration in addition to the reservoir fluid properties. Reservoir parameters adjustment realistically is also needed to obtain a good geological model. Real field production data is likewise essential to validate the geological model during the history matching process between the observed data and the simulation cases. Finally, different forecasting scenarios are necessary to achieve the most proper management method for the current and future existence of the hydrocarbon field.

1.1 Reservoir modelling using Petrel

Petrel is software which acts as a single platform for collecting different disciplines together like geophysics, geology, reservoir engineering, etc. and assisting in the solution of the subsurface challenges and problems from the early stages of exploration to the oil field development. The most complicated reservoir model does not mean necessarily the better simulation results. It is better to keep the model simple. Start and end with the simplest model which is consistent with the reservoir nature, tasks' objectives and data availability (Aziz K. 1989). The simple gridding method (without faults) has been used in this investigation for making the reservoir model despite that there are two other methods available in Petrel (corner point gridding and structural framework) in which faults can also be modeled. Another positive mechanism in Petrel is its connectivity with the simulators in a way that Petrel convert all the data to the simulator data file format and the possibility of playing with the simulator keywords via editor tab in define simulation case domain tab. Eclipse Black Oil is one of the simulators which Petrel can connect to and it has been used in this research.

1.2 Reservoir simulation using Eclipse Black Oil

Eclipse is reservoir simulator which has been introduced first in 1983 at Society of Petroleum Engineers conference in San Francisco - United States of America - and it is used by almost all oil companies since that time and also by many governmental agencies (Schlumberger 2014). Eclipse is processing the input data to a form which is more convenient for the flow calculations (Schlumberger 2014). In addition to that, Eclipse has an auxiliary package which allows the user to connect it with other platforms like Petrel Reservoir Engineering (Schlumberger 2014). Each simulation analysis is unique and selecting the simulator type depends on the data availability and the aim of the investigation. In this research, Eclipse 100 (Black Oil) has been selected because the priority has been given to the crude oil itself and not to its components. Finally, Eclipse is just a tool which designed to aid its users in their interpretation for the simulation results and should not substitute the mankind judgment.

1.3 Previous investigation

As an extra task from the very beginning of the enrollment as a doctorate and before starting the work on the main investigation case which is Taq Taq oil field in the Kurdistan region of Iraq, a reservoir simulation analysis has been carried out for Rotterdam oil field in south west of Netherlands.

The data is available for the public use and the information about Netherlands oil and gas fields can be found in Netherlands oil and gas portal. Rotterdam oil field unlike Taq Taq oil field, its reservoir is consisting of sandstone rocks and containing twenty one wells which some of them are horizontal wells. The first well had been drilled in 1984. The reservoir pressure was 162 bars and the reservoir temperature was 65 C° with API gravity of 35 in 2003. It is important to mention that the observed production data for Rotterdam oil field which has been used in this case was from 2003 to 2016 in a monthly way for water, oil and gas. Single porosity simulation analysis has been conducted.

This extra task has been published in the Society of Petroleum Engineers – Student technical conference November 2017 in Clausthal – Germany as presentation under the title of **"History Match and Prediction: A Reservoir Simulation Sensitivity Based Study of Rotterdam Oil Field"**. In the mentioned presentation the steps of building the three dimensional geological model has been discussed and how its difficulties have been fixed. In addition to that, the matching case achievement was presented and also the prediction case for both oil and gas. After a lot of investigations, the most influential parameter on the history matched case was the reservoir thickness. The prediction case was run from 2016 to 2030 which showed a gentle decline in oil production rate.

1.4 Taq Taq oil field

Generally the recent hydrocarbon field explorations in the Kurdistan region – Iraq started since 2003. Taq Taq oil field has been discovered before 2003 but the operations started again systematically in 2002. It has been selected for this investigation due to some reasons including: Taq Taq oil field is one of the very few oil fields in Kurdistan region which has a history production data for more than one well, it has a very challenging and complicated reservoir which consists of low matrix porosity and low matrix permeability and highly fractured carbonate reservoir, as the field in its early production period, it was very important to conduct this research to avoid any improper development and production management. The figure 1.1 below shows the location of Taq Taq oil field (the red star) and the green lines shows the old and new transportation pipelines in the region.

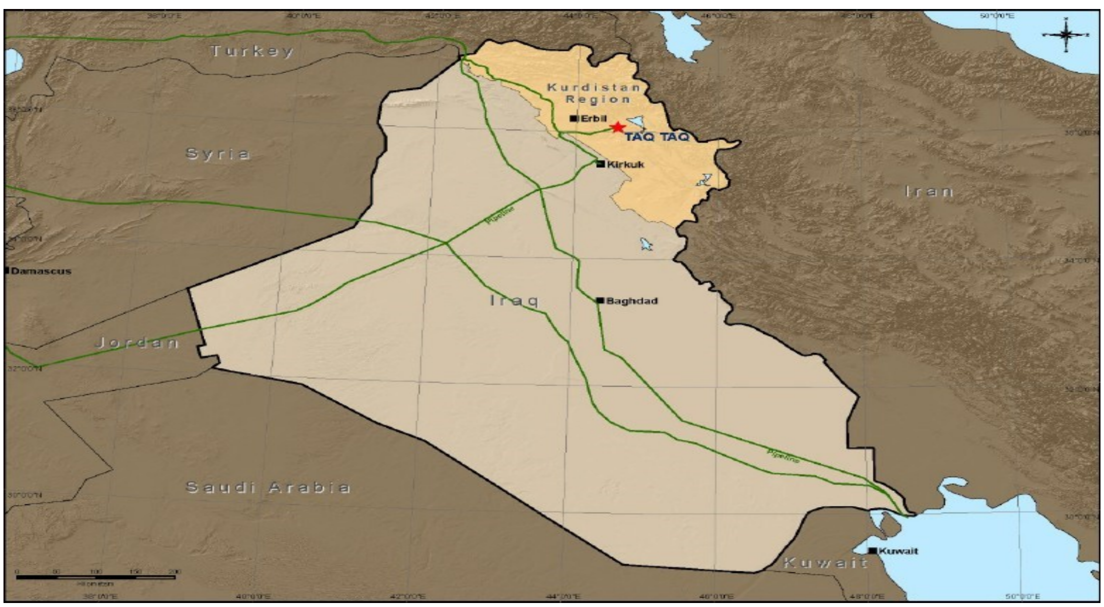


Figure 1.1 Geographical location of Taq Taq oil field in the Kurdistan region – Iraq

Source of the map: McDaniel & Associates Consultants Ltd., GENEL ENERGY INTERNATIONAL LTD, Competent Person's Report – Taq Taq oil field, December 2015

1.5 Goals of the investigation

1. Making three dimensional geological model for the reservoir which is reliable for further analysis by calibrating it with the historical production data (history matching) which lead to a better understanding of the reservoir in terms of the heterogeneity of the reservoir porosity and permeability, reservoir fluid properties, and the reservoir driving mechanisms.
2. Predicting the reservoir future performance under the required production conditions which gives a comprehensive view for the prospect behavior of the field.
3. Proper development planning, strategy and management by controlling the rates of production in a way which suits the reservoir performance and the market's demand.
4. Determining new well locations, spacing between the wells and the completion design in a way which assists in increasing the oil recovery.
5. Re-injecting the produced associate gas and identify its effect on the recovery instead of flaring it.
6. Suggesting the optimum method of enhanced oil recovery which will be required in the later stages of the reservoir life period.

1.6 Chapters' layout

This dissertation consists of five chapters. In chapter two a detailed description of the studied reservoir in Taq Taq oil field will be presented in addition to the history of the field. Chapter three will cover the workflow and telling about the procedure of making the three dimensional geological model with its static and dynamic properties and also the process of running the simulation cases. Chapter four will present the results of the simulation. The first part of chapter four will discuss the results of the history match simulation cases and how the matched case has been obtained for oil, gas, wellhead and bottom hole pressure and the second part of chapter four will present the results of the prediction cases also for oil, wellhead and bottom hole pressure. Finally, chapter five will come up with conclusions and some recommendations.

2. Reservoir description

2.1 History of Taq Taq oil field

Taq Taq oil field is located 50 kilometer South East of the capital of Kurdistan region – Iraq (Erbil). The first drilling activities have been started in 1958 by SAIPEM (Società Anonima Italiana Perforazioni E Montaggi) for the North Oil Company (NOC). TT-01 drilling has been stopped shortly after spudding in 1961 and the drilling processes re-started again in 1978 and finished in the same year after reaching the total depth of 3986 m (Akça L. et al 2006).

TT-02 is about 150 m far from (East of) TT-01. It has been drilled in 1978 with a total depth of 663 m. TT-03 is located about 2 km South West of TT-01 and spudded in 1980. This well has not been completed due to mechanical problems and it has been suspended with a fish in the hole (Akça L. et al 2006).

TT-01 and TT-02 started to produce crude oil in 1996 till 2004 with a total of 4 and 1.15 million stock tank barrel respectively. After the separation processes in the oil field, the produced oil had been transported to a local refinery in Sulaimaiyah city by tanker truck (3 to 4 tanker truck per day) (Akça L. et al 2006).

It is important to mention that the rest of the wells have been drilled after 2005 by the current operator TTOPCO (Taq Taq Operation Company) and currently Taq Taq oil field contains 31 wells. TT-01 has been abandoned, TT-03 left since 1980 with a fish in the hole, TT-02, TT-11, TT-25, TT-26, TT-30 and TT-31 are producing from Pilaspi Formation which its depth is about 600 m and this part of the oil field will not be considered in this research. TT-22, TT-23, TT-24, TT-27, TT-28 and TT-29 have not been included due to the lack of data.

Table 2.1 shows the number of the current existing wells in Taq Taq oil field with their total depths, spudded date, date at which total depth reached and the pay zone (reservoir).

Table 2.1 Wells, Total depth, starting date, Finishing date and the Pay zone's name of Taq Taq oil field

Well name	Total depth	Spud date	Date TD was reached	Reservoir
TT-01	3986	1961	1978	Shiranish/Kometan/Qamchuqa
TT-02	663	13/06/1978	01/07/1978	Pilaspi
TT-03	N/A	1980	N/A	N/A
TT-04	2286	13/05/2006	26/08/2006	Shiranish/Kometan/Qamchuqa
TT-05	2070	23/10/2006	20/12/2006	Shiranish/Kometan/Qamchuqa
TT-06	2265	08/01/2007	06/04/2007	Shiranish/Kometan/Qamchuqa
TT-07	2187	30/04/2007	03/07/2007	Shiranish/Kometan/Qamchuqa
TT-08	2366	19/07/2007	12/12/2007	Shiranish/Kometan/Qamchuqa
TT-09	2444	30/08/2007	02/11/2007	Shiranish/Kometan/Qamchuqa
TT-10	2247	14/08/2008	13/12/2008	Shiranish/Kometan/Qamchuqa
TT-11	1000	04/09/2008	30/09/2008	Pilaspi
TT-12	2179	12/12/2010	21/04/2011	Shiranish/Kometan/Qamchuqa
TT-13	2227	27/04/2011	11/07/2011	Shiranish/Kometan/Qamchuqa
TT-14	2354	14/07/2011	26/08/2011	Shiranish/Kometan/Qamchuqa
TT-15	2170	27/08/2011	25/10/2011	Shiranish/Kometan/Qamchuqa
TT-16	2392	29/10/2011	07/01/2012	Shiranish/Kometan/Qamchuqa
TT-17	2300	08/01/2012	28/03/2012	Shiranish/Kometan/Qamchuqa
TT-18	2175	24/10/2012	05/01/2013	Shiranish/Kometan/Qamchuqa
TT-19	2375	28/03/2012	30/06/2012	Shiranish/Kometan/Qamchuqa
TT-20	2422	15/06/2013	17/08/2013	Shiranish/Kometan/Qamchuqa
TT-21	2370	02/04/2013	30/05/2013	Shiranish/Kometan/Qamchuqa
TT-22	5427	27/03/2013	19/01/2014	Shiranish/Kometan/Qamchuqa
TT-23	N/A	N/A	N/A	N/A
TT-24	N/A	N/A	N/A	N/A
TT-25	579	06/10/2013	15/02/2014	Pilaspi
TT-26	582	30/10/2013	20/12/2013	Pilaspi
TT-27	N/A	N/A	N/A	N/A
TT-28	N/A	N/A	N/A	N/A
TT-29	3100	N/A	Early September 2017	Shiranish/Kometan/Qamchuqa
TT-30	N/A	N/A	N/A	Pilaspi
TT-31	N/A	N/A	N/A	Pilaspi

2.2 Geology of Taq Taq oil field

2.2.1 Tectonic and structural geology of the area

2.2.1.1 Tectonic

The Iraqi Kurdistan region is located on the border area between the Nubio – Arabian platform and Asian part of the Alpine Geosyncline. Toros mountains in the north and Zagros mountains from the south to the north of Kurdistan region – Iraq are considered to be parts of the Asian Alpides. Generally, Iraq is divided in to two main parts in term of tectonic which are stable and unstable shelfs. The stable shelf is classified in to three main subzones; the western subzone, the north – south trending which is called Abu Jir and Shbicha subzone. It is worthy to say that each subzone is divided to some other blocks (Buday et al 1980).

The unstable shelf is classified in to three subzones also which are the outer, central and innermost units. The outer subzone which is also called Mesopotamian zone is characterized by slight folding in the sedimentary cover and has been divided in tow to parts; the southwestern Euphrates and the northeastern Tigris part. The central unit is called the foothill zone which characterized by well folded and thick sedimentary layers. It is also characterized by narrow long anticlines and broad flat synclines. The foothill zone is divided in to three parts; the Makhul subzone in the southwest, Kirkuk and Qalian subzones in the center and Chemchemal subzone in the northeast. It is very important to mention that the Taq Taq oil field is located in the foothill zone and specifically in Chemchemal subzone (Buday et al 1980).

In addition to the two main tectonic zones (stable and unstable shelfs) there is another narrow stripe of the Alpine Geosyncline which is divided in to two subzones called Imbricated zone and Zagros thrust zone which represent the Mio-geosyncline and Eu-geosyncline parts of the Alpine narrow stripe in the north and north east of the Iraqi Kurdistan region respectively. This narrow stripe is characterized by a very complex structure and stratigraphy (Buday et al 1980).

2.2.1.2 Structural geology

As mentioned before, Taq Taq oil field is located in the foothill zone which characterized by narrow long anticlines and broad flat synclines with a thick sedimentary cover. Taq Taq structure is consists of an anticline accompanied by two major revers fault. The anticline length is about 27 km and its width is about 11 km on the surface. The flanks have dip angle ranged from 5 – 19 degree toward east and 7 – 23 degree to the west. The structure of Taq Taq oil field is related to the compressive phase of Zagros Mountain building. The general trend of the stress is North-North West and South-South East which can be noticed in the major open fracture orientations (Akça L. et al 2007).

The figure 2.1 below is representing the SW – NE seismic cross section with a detailed interpretation of the main reflectors and the structure of Taq Taq oil field.

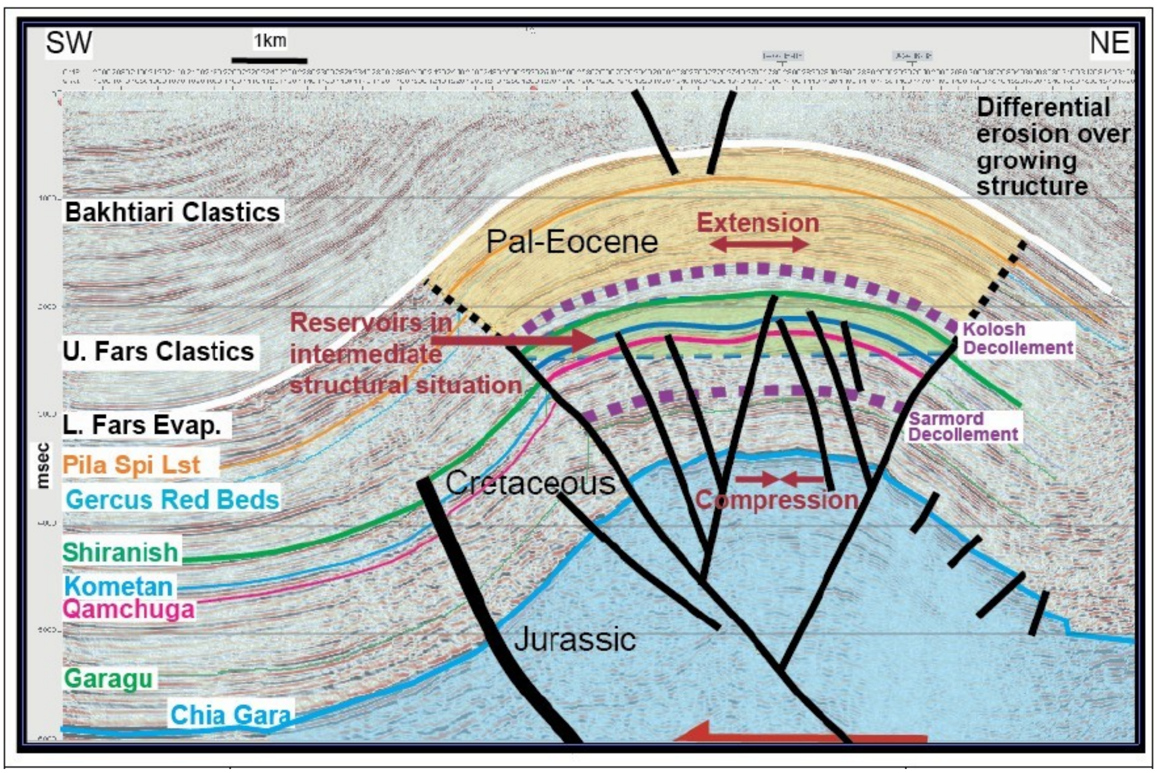


Figure 2.1 Taq Taq oil field structure and the major reflectors in a cross section.

2.2.2. Depositional environment and stratigraphy

2.2.2.1 Depositional environment

Generally the depositional environment of the area is marine (continental margin) environment (Akça L. et al 2007). The region underwent several transgression and regression of the sea as well as several uplift and subsidence through the Geological time which led to the formation of the current geological setting of the area. According to the cutting samples and the well logs, a certain geological column has been recognized during the development of Taq Taq oil field. Qamchuqa formation is located at the very bottom of the geological column which has been detected during the drilling process of the wells. The depositional environment of this formation is neritic and sometimes shoal. It has a large distribution which comprises the stable and unstable shelfs. Qamchuqa formation is overlaying by Dokan limestone formation which has been deposited in an open sea environment. Dokan formation has a relatively restricted distribution and it can be seen in the high folded zone and foothill zone. Gulneri shale formation is overlaying Dokan limestone formation and it has been deposited in an euxinic environment which characterized by no oxygen content and the existence of hydrogen sulfide and the distribution of the formation is almost unknown (Buday et al 1980).

Kometan formation is one of the main reservoir zones in Taq Taq oil field and it has been deposited in a deeper neritic open sea environment. Kometan formation is widely distributed in the imbricated zone, the high folded zone and the foothill zone. Shiranish formation is another reservoir zone which overlaying Kometan formation. The depositional environment of Shiranish formation is typical deeper open sea. It is widely distributed in the Kurdistan region territories. Aaliji formation is deposited in off-shore open sea between neritic – shoal area on the slopes of the platform and the marginal uplift marked by the reefs. It is distributed on the foothill zone and the northern part of the Mesopotamian zone. It is important to mention that this formation is acting as a cap rocks (Buday et al 1980).

Kolosh formation is consists of sediments which is deposited in a rapidly sinking trough of near – shore neritic environment. The extension of Kolosh formation can be seen in the foothill zone and the marginal part (southwest) of the high folded zone. Sinjar limestone formation is another carbonate unit in the geological column which found in the Taq Taq oil field. The depositional environment is shoal specifically characterized by reef, back – reef and fore – reef sediments. The formation has irregular distribution. Khurmala formation has a lagoonal depositional environment and it has a restricted distribution. Gercus formation was deposited in a relatively wide sinking molasses trough and it distribute in the foothill zone and the high folded zone also. Pilaspi limestone formation is considered as another pay zone in Taq Taq oil field and it contains heavy oil. It has been deposited in an inshore and lagoonal environment. It has somehow the same distribution as Gercus formation. The lower Fars formation is deposited in a toughly sinking basin which separated by ridges from the open sea. It has a wide distribution which covers the entire unstable shelf and the marginal area of the unstable shelf. The last formation in our geological column is the upper Fars formation which considers being the youngest geological unit in the series of the units which has been detected during the drilling process. It has a varied depositional environments starting from lagoon to lacustrine and finally fluvio – lacustrine and it can be found in the foothill zone as well as the Mesopotamian zone also (Buday et al 1980).

During the drilling activities, in some well locations, the drilling started to penetrate the upper Fars formation directly and there was no any recent deposit. In some other well locations there was a thin layer of Bakhtiari formation which consists of recent deposit generally and it is younger than upper Fars formation in term of geological age. The entire geological column has not been penetrated in all of the wells. Some wells were drilled to the bottom of Kometan formation and in some other wells the Dokan and Gulneri formations have not been detected clearly due to the very low thickness. In some other wells Kolosh and Aaliji formation have been considered as one unit (Kolosh formation). Table 2.2 is showing the succession of the geological formation in each well with their thickness (measured), measured depth, interval depth (measured) and true vertical depth.

Table 2.2 The geological column with their thicknesses and depths

Wells	TT-04				TT-05				TT-06			
Formations	Top (MD)	Bottom (MD)	Thickness (MD)	True depth at the bottom of the Formation AMSL (m)	Top (MD	Bottom (MD)	Thickness (MD)	True depth at the bottom of the Formation AMSL (m)	Top (MD	Bottom (MD)	Thickness (MD)	True depth at the bottom of the Formation AMSL (m)
Upper Fars	surface	257.5	257.5	355.5	surface	246.5	246.5	366.5	surface	332	332	258
Lower Fars	257.5	534	276.5	79	246.5	525.5	279	87.5	332	602.5	270.5	-12.5
Pilaspi	534	644.5	110.5	-31.5	525.5	636	110.5	-23	602.5	711	108.5	-121
Gercus	644.5	718.5	74	-105.5	636	699	63	-86	711	779	68	-189
Khurmala	718.5	826.5	108	-213.5	699	799.5	100.5	-186.5	779	885	106	-295
Sinjar	826.5	899.5	73	-286.5	799.5	869.8	70.3	-256.7	885	941	56	-351
Kolosh	899.5	1082	182.5	-469	869.8	1095	225.2	-482	941	1111	170	-521
AALIJI	1082	1608	526	-994.7	1095	1630.5	535.5	-1017.5	1111	1659	548	-1069
Shiranish	**1608**	**1857**	**249**	**-1243.6**	**1630.5**	**1988**	**357.5**	**-1378**	**1659**	**1957.5**	**298.5**	**-1366.8**
Kometan	**1857**	**1948.5**	**91.5**	**-1335.1**	**1988**	**2070.6**	**82.6**	**-1453.8**	**1957.5**	**2054**	**96.5**	**-1463**
Gulneri	1948.5	1956.3	7.8	-1342.9	X	X	X	X	2054	X	X	X
Dokan	1956.3	1957.4	1.1	-1344	X	X	X	X	X	2071.5	X	-1480.3
Quamchuqa	1957.4	2286	328.6	-1672.6	X	X	X	X	2071.5	2265	193.5	-1673.3
	TT-07				TT-08				TT-09			
Upper Fars	surface	255	255	300	surface	252	252	296.5	surface	332.5	332.5	190.5
Lower Fars	255	543.5	288.5	11.6	252	531	279	17.5	332.5	561.5	229	-38.5
Pilaspi	543.5	662	118.5	-106.9	531	637	106	-88.5	561.5	677	115.5	-154
Gercus	662	725	63	-169.6	637	711	74	-162.5	677	749.5	72.5	-226.5
Khurmala	725	843.5	118.5	-286.5	711	811	100	-262.5	749.5	865	115.5	-342
Sinjar	843.5	962	118.5	-401.5	811	903	92	-354.5	865	1027.5	162.5	-504.5
Kolosh	962	1186	224	-620	903	1583.5	680	-1035.5	1027.5	1635.5	608	-1111.5
AALIJI	1186	1661.5	475.5	-1082	X	X	X	X	X	X	X	X
Shiranish	**1661.5**	**1911**	**249.5**	**-1324**	**1583.5**	**1925**	**341.5**	**-1375.7**	**1635.5**	**1905**	**269.5**	**-1381**
Kometan	**1911**	**2010**	**99**	**-1418.5**	**1925**	**2046**	**121**	**-1497**	**1905**	**2001.5**	**96.5**	**-1476**
Gulneri	2010	2020	10	-1428.5	2046	2050	4	-1501	2001.5	2006.5	5	-1481
Dokan	2020	2025	5	-1432.5	2050	2054	4	-1504	2006.5	2009.5	3	-1484
Quamchuqa	2025	2186.85	161.85	-1587.25	2054	2366	312	-1817.5	2009.5	2444	434.5	-1917.5

2.2.2.2 Stratigraphy

In this section the stratigraphy of the Taq Taq oil field will be covered in terms of the geological age of each geological unit (formation), lithology and the boundary type. Generally the geological formations which are considered as reservoirs in Taq Taq oil field are carbonate rocks. On the other hand, the non-reservoir formations are consisting of clastic rocks. The table 2.3 below shows the geological age and contacts' type of each formation which has been penetrated during the drilling processes.

Table 2.3 Geological age, upper and lower contact type

Formations	Geological Age	Upper contact	Lower contact
Upper Fars	Upper Miocene	Diachronous	Gradational
Lower Fars	Middle Miocene	Gradational	Conformable / slight unconformities in some areas
Pilaspi	Middle to Upper Eocene	Unconformable	Gradational
Gercus	Lower Eocene to Early Upper Eocene	Conformable	Marked by a break
Khurmala	Paleocene to Lower Eocene	Erosional and unconformable	Gradational
Sinjar	Upper Paleocene	Not clear (Ditmar et al. 1971)	Unconformable
Kolosh	Paleocene	Unconformable	Unconformable
Aaliji	Paleocene to Lower Eocene	Unconformable	Unconformable
Shiranish	Upper Campanian to Maastrichtian	Erosional	Conformable
Kometan	Lower Turonian to Santonian	Unconformable / sometimes seemingly conformable	Unconformable
Gulneri	Lower Turonian	Unconformable	Unconformable
Dokan	Cenomanian	Unconformable	Unconformable
Qamchuqa	Albian	Marked by a break	Conformable

Pilaspi formation is considered as one of the oil bearing zones in Taq Taq oil field. The age of the formation is middle to upper Eocene (Tertiary). The upper boundary which is the contact between Pilaspi and Lower Fars formation is unconformable whereas the lower contact with the Gercus formation is gradational. The Marl and Anhydrite in the Lower Fars formation is acting as a cap rock for Pilaspi formation. Generally Pilaspi formation is consist of Dolomitic Limestone, Argillaceous Limestone, Dolomite, Claystone, Anhydrite and Chert. This formation is about 600 meter deep and about 110 to 120 meter thick which contains heavy oil and it has not been covered in this research for the reservoir simulation and management.

Shiranish and Kometan formations are considered to be the second oil bearing zones in Taq Taq oil field. The age of Shiranish formation is upper Campanian to Maastrichtian whereas Kometan formation is Lower Turonian to Santonian (Cretaceous). The upper boundary of Shiranish formation with Aaliji (in some places Kolosh formation) is erosional and due to the existence of Claystone, Shale and Marl in the overlying formations, it behave as a cap rocks for Shiranish formation. The lower contact of Shiranish formation with the underlying formation which is Kometan formation is conformable. The cutting and well logs of some wells are showing Shale between Shiranish and Kometan formation. It is important to mention that the formation micro image FMI demonstrate an intensive fracture system in both formation. Generally, Shiranish formation consists of Argillaceous Limestone, Limestone, Siltstone, Lime Mudstone, Shale and Marl whereas Kometan formation is consisting of Limestone, Dolomite, Shale, Claystone and Dolomitic Limestone. The thickness of Shiranish and Kometan formations are 250 – 350 meter and 80 – 100 meter respectively in Taq Taq oil field as detected from the cutting samples and well logs. The true vertical depth below mean sea level of Shiranish and Kometan formations are -1240 to -1380 meter and -1335 to -1500 meter respectively. Taq Taq oil field is about 600 meter above mean sea level. Those two formations are considered in this research for reservoir simulation and management.

The age of Gulneri formation is Lower Turonian and both upper and lower boundaries are unconformable. It is mainly consist of Claystone which appear obviously in all of the well logs. Gulneri formation is 7 to 10 meter thick. Dokan formation is underlying Gulneri formation and its age is Cenomanian. Both upper and lower boundaries are unconformable. Dokan formation is about 1 to 5 meter thick which consist mainly of Limestone.

The last formation which has been penetrated by some wells is Qamchuqa formation. The age of Qamchuqa formation is Albian. The upper boundary has been marked by a break. The formation is consists of Dolomitic Limestone, Limestone, Dolomite, Calcareous Claystone and Claystone. The table 2.4 below is showing the lithology of all the formation which have been penetrated in Taq Taq oil field and the order of the rock types in the table do not reflect the real sequence.

Table 2.4 lithology of the geological formation in Taq Taq oil field

Formations	Lithology
Upper Fars	Claystone, Siltstone, Sandstone, Marl, Anhydrite
Lower Fars	Claystone, Siltstone, Marl, Anhydrite, Limestone
Pilaspi	Dolomitic Limestone, Argillaceous Limestone, Dolomite, Claystone, Anhydrite, Chert
Gercus	Claystone, Siltstone, Conglomerate, Limestone, Argillaceous Limestone, Dolomite, Chert, Sandstone, Dolomitic Limestone, Anhydrite
Khurmala	Dolomitic Limestone, Claystone, Limestone, Dolomite, Chert, Argillaceous Limestone, Siltstone, Sandstone, Anhydrite
Sinjar	Dolomitic Limestone, Limestone, Siltstone, Sandstone, Calcareous Claystone, Argillaceous Limestone
Kolosh	Siltstone, Limestone, Marl, Calcareous Claystone, , Calcareous Siltstone, Chert
Aaliji	Claystone, Siltstone, Sandstone, Marl, Shale, Limestone
Shiranish	Argillaceous Limestone , Limestone, Siltstone, Lime Mudstone, Shale, Marl
Kometan	Limestone, Dolomite, Shale, Claystone, Dolomitic Limestone
Gulneri	Claystone, Argillaceous Limestone
Dokan	Limestone
Qamchuqa	Dolomitic Limestone, Limestone, Dolomite, Calcareous Claystone, Claystone

2.3 Reservoir data

As it is mentioned before, Taq Taq oil field contains 31 wells so far. Six of them are just penetrated Pilaspi formation which its depth is about 600 meter and contains heavy oil. Pilaspi formation has not been considered in this research. TT-01 has been abandoned after Taq Taq operation company (TTOPCO) started its operation in Taq Taq oil field in 2002 and TT-09 has been drilled close to the location of TT-03 which has been left with a fish in the hole in 1980. The rest of the wells (25 wells) are penetrated the Shiranish and Kometan formation whereas some of the wells penetrated Gulneri, Dokan and the upper part of Qamchuqa formations too.

The data which has been provided by the Ministry of Natural Resources of Kurdistan Regional Government for this research included six wells (TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09). The data consists of the final well report of each well for those six wells, composite well logs, formation micro imager (FMI) log of TT-05, TT-06 and TT-07, PVT (pressure, volume and temperature) analysis report of TT-07 and production data from 23/05/2010 to 05/05/2011 for the six wells. The production of Taq Taq oil field was only from those six wells (TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09) till 23/05/2011.

The mentioned data has been used as a raw material for this research. All the necessary parameters have taken from those data to make the required data file from them in order to use it in Petrel to make the 3D geological model and preparing it for the simulation by using Eclipse. In this section the fracture data, the porosity data (matrix porosity), Gamma ray logs, the production (oil, gas, water, gas/oil ratio and well head pressure) and reservoir fluid data for Shiranish and Kometan formation will be presented.

2.3.1 Fracture data

The fracture data has been taken from the formation micro imager log (FMI) of the wells TT-05, TT-06 and TT-07. The interpretation of the FMI logs has been done by the Fugro Robertson Limited. The fractures have been classified into several types like bedding, stylolite, etc. and also the dip direction and dip azimuth have been determined. Each fracture type has a certain code which is very useful in term of the data interpretation in Petrel. The table 2.5 below is showing the fracture type with their code and the amount (number) of each type which has been detected during the FMI log interpretation from TT-05, TT-06 and TT-07 for Shiranish and Kometan formation.

Table 2.5 The fracture type, code and number of TT-05, TT-06 and TT-07 in Shiranish and Kometan formation

Fracture code	Fracture type	In Shiranish formation	In Kometan formation	Total number
1000	Bedding, high conf.	78	24	102
1002	Bedding, low conf.	48	28	76
1003	Stylolite	1	8	9
1034	Solution feature? Karst or HT dol related	1	6	7
1040	Hardgrounds, scour bases etc.	3	1	4
1050	?Cem.-resistive frac, high conf.	7	1	8
1052	?Cem.-resistive frac, discontinous	28	1	29
1070	Mud pressure ind. frac., high conf.	65	9	74
1072	Mud pressure ind. frac., low conf./discontinous	246	77	323
1080	?Open/conduct. frac., high conf.	50	68	118
1082	?Open/conduct. frac, discontinous	193	338	531
1090	>15 cross beds/forsets, high conf.	0	4	4
1100	Breakout frac, high conf.	2	0	2
1102	Breakout frac, low conf.	0	3	3
3050	Cem.-resistive fault, high conf.	6	1	7
3060	Neut contrast fault (?soft sed.), high conf.	17	2	19
3061	Neutral contrast fractures, continuous	48	2	50
3062	Neutral contrast fractures, discontinuous	141	62	203
3080	?Open-conductive fault, high conf.	19	9	28
Total		953	644	1597

Regarding the dip angle and dip azimuth, the data has been analyzed using Microsoft excel and Petrel. The average dip angle has been calculated for all the three wells in both Shiranish and Kometan formation. For example the average dip angle in TT-05 in Shiranish formation is 53.55 degree whereas in Kometan formation is 55.82 degree and the average dip angle in well TT-05 is 54.69 degree. The table 2.6 below is presenting the average dip angle in each well, each well in each formation, each formation and in general.

Table 2.6 Average dip angle

Zone	Average Dip Angle (degree)
TT-05	54.69
TT-06	72.41
TT-07	60.94
TT-05 in Shiranish formation	53.55
TT-05 in Kometan formation	55.82
TT-06 in Shiranish formation	72.87
TT-06 in Kometan formation	71.95
TT-07 in Shiranish formation	66.07
TT-07 in Kometan formation	55.82
Shiranish formation	64.71
Kometan formation	61.19
General Dip average	62.68

Regarding the dip directions, they have been plotted on a Rose diagram in Petrel to have a better visualization of the data and to know the general dip direction in each well, each well in each formation, each formation and in general. For instance, the general dip direction in TT-06 is North West – South East. The general dip direction in TT-06 in Shiranish formation is South East and in Kometan formation is North West. From the Rose diagram plots, it is clear that the fracture orientation has been affected by the general trend of the structures in the region and they are very important for making the discrete fracture network (DFN) in Petrel and making fracture properties later on and involving them in a dual porosity and permeability reservoir simulation. The figures 2.2 and 2.3 below are presenting the dip direction and the colors (in the Rose diagrams) representing the fracture types.

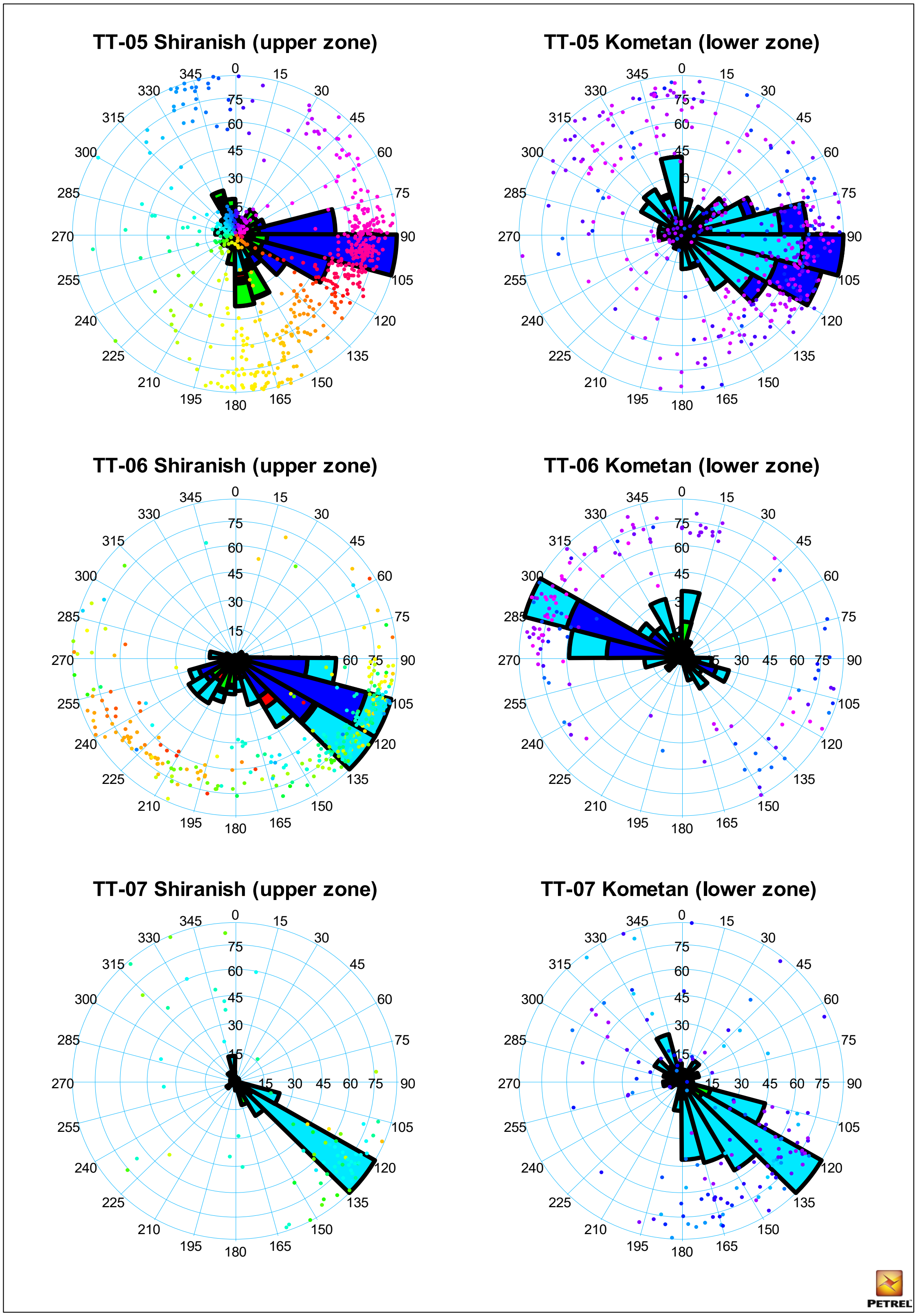


Figure 2.2 dip direction of each well in each formation

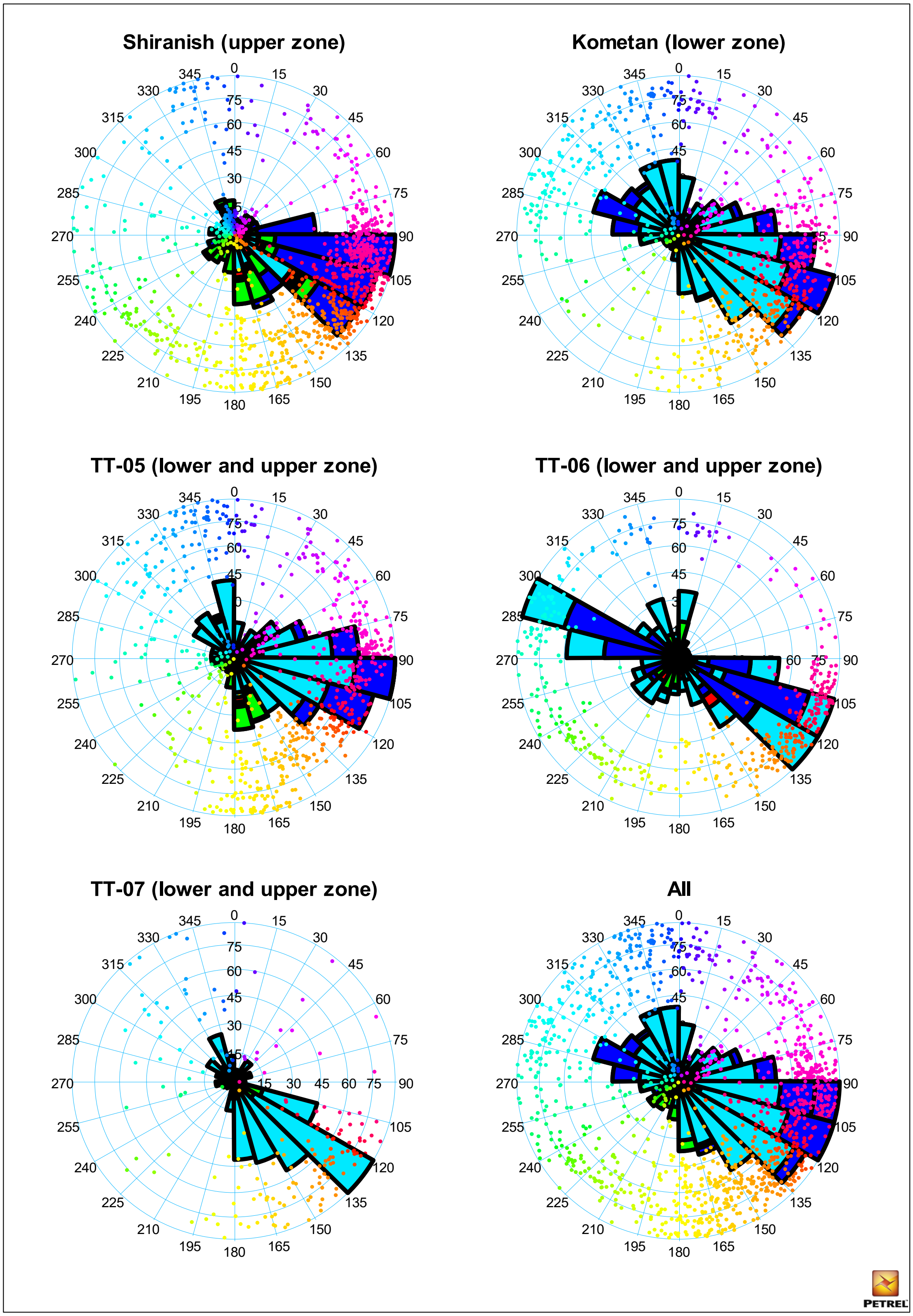


Figure 2.3 dip direction in each formation, each well and in general

2.3.2 Matrix porosity and natural radiation well log

The well log data has been provided by the Ministry of Natural Resources of Kurdistan Regional Government for the wells TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09 as a pdf file. Didger 5 has been used to digitize the well log data and creating the Log ASCII Standard (LAS) file which has been used later on in Petrel to make the property modeling. Two well logs are digitized which are neutron porosity and gamma ray logs in both Shiranish and Kometan formations.

The neutron porosity well logs are showing very low matrix porosity in Kometan formation and a little bit higher matrix porosity than Kometan formation in Shiranish formation in all of the six wells. There is an increase in the gamma ray log values at the bottom of the Shiranish formation in all of the six wells which is consider as an indication of the shale content. It has been interpreted as a wackestone in TT-04 which is mud-supported carbonate lithology containing more than 10 percent grain (Dunham 1962). Packstone has been recognized at the top of Kometan formation in TT-04 which is a grain supported fabric containing one percent or more mud grade fraction (Dunham 1962). It is important to mention that some Shale layers interbedded with Limestone has been detected at the bottom of Shiranish and the top of Kometan formations in TT-05. In TT-06 the Shale content in the limestone at the bottom of Shiranish formation is relatively high and it has been interpreted as mudstone which is a mud supported carbonate rock contains less than 10 percent grain (Dunham 1962). In TT-07 the Shale content is less in comparison with the other five wells in both bottom of Shiranish and top of Kometan formation. In TT-08 at the bottom of Shiranish formation there was mud loss which indication of a big fracture corridor and the limestone in Kometan formation has been interbedded with some claystone and sand layers. Also TT-09 shows some Shale content at the bottom of Shiranish formation. Figure 2.4 and 2.5 show the gamma ray and neutron porosity logs for all of the six wells. The light blue color curve is the gamma ray values of Shiranish formation and the dark blue is the gamma ray values of Kometan formation. The light red color curve represents the neutron porosity in Shiranish formation whereas the dark red is the neutron porosity values in Kometan formation.

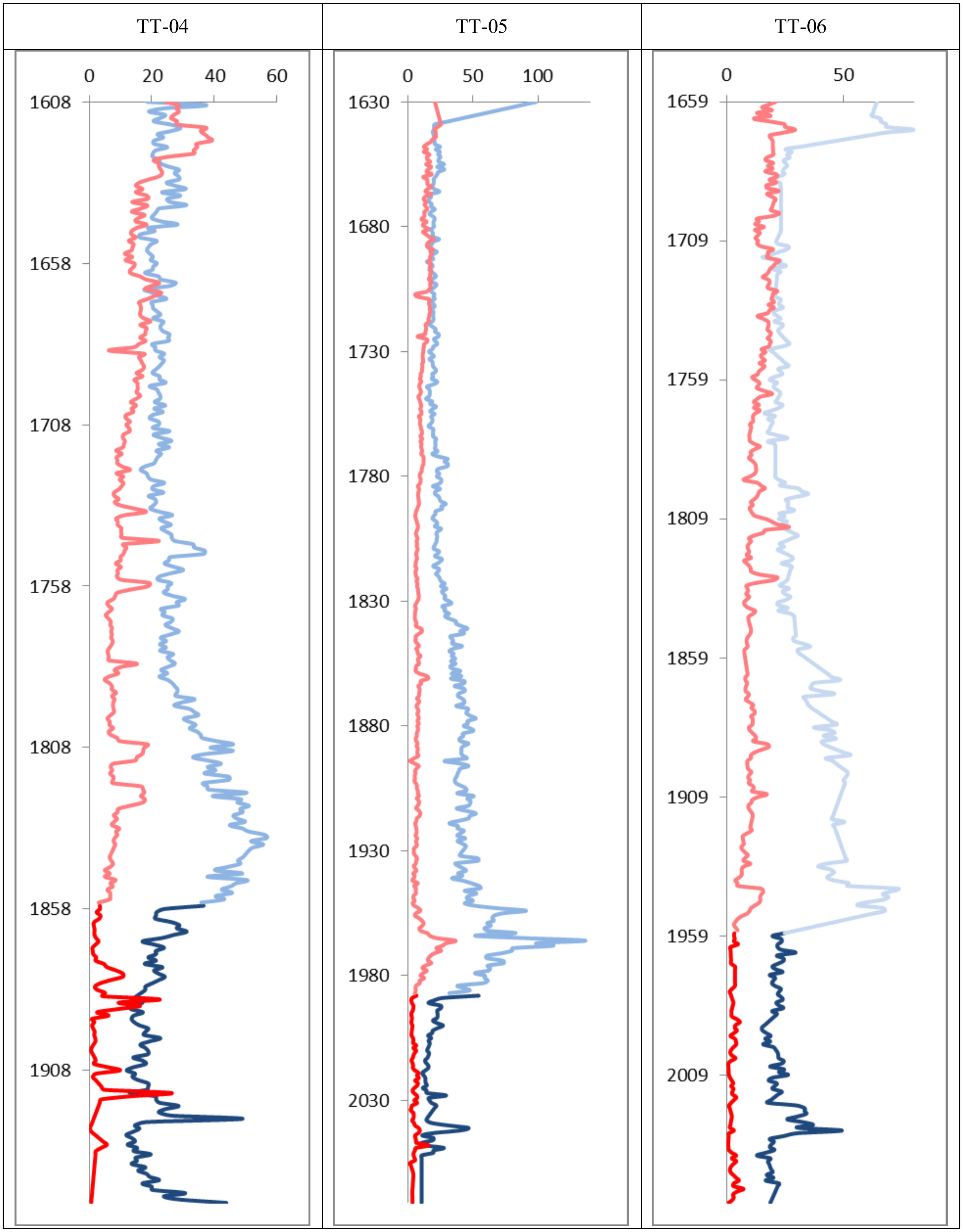


Figure 2.4 the gamma ray and neutron porosity in TT-04, TT-05 and TT-06

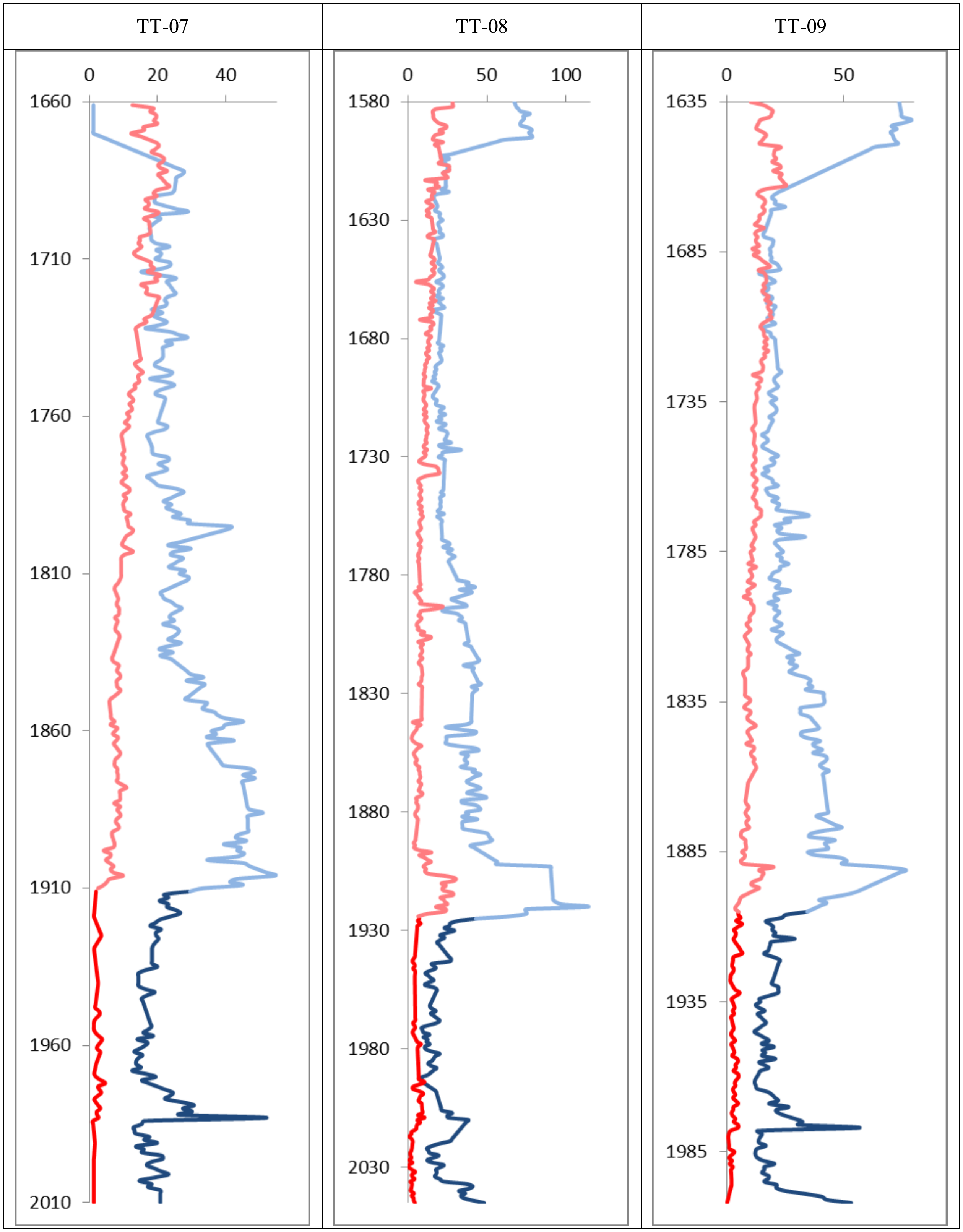


Figure 2.5 the gamma ray and neutron porosity in TT-07, TT-08 and TT-09

2.3.3 Production data

The production data has been provided as an Excel sheet files including the oil, gas and water daily production rates from May 23rd 2010 to May 5th 2011 in addition to their daily, monthly and yearly cumulative rates for the wells TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09. It includes also the well head pressure, well head temperature, the API gravity, period of production per day and the gas oil ratio. It is clear from the well completion data that the perforations have been created against the Shiranish and Kometan formation and packers have been set between both formations in the completion in each of the six wells. It is very obvious in the data file that the production was only from Kometan formation. The well head pressure data varies between 400 to 800 psi which have been converted later on to bottom hole pressure using Hagedorn – Brown correlation method and the figure 2.6 below is showing the well head pressure of each well for the period that mentioned above.

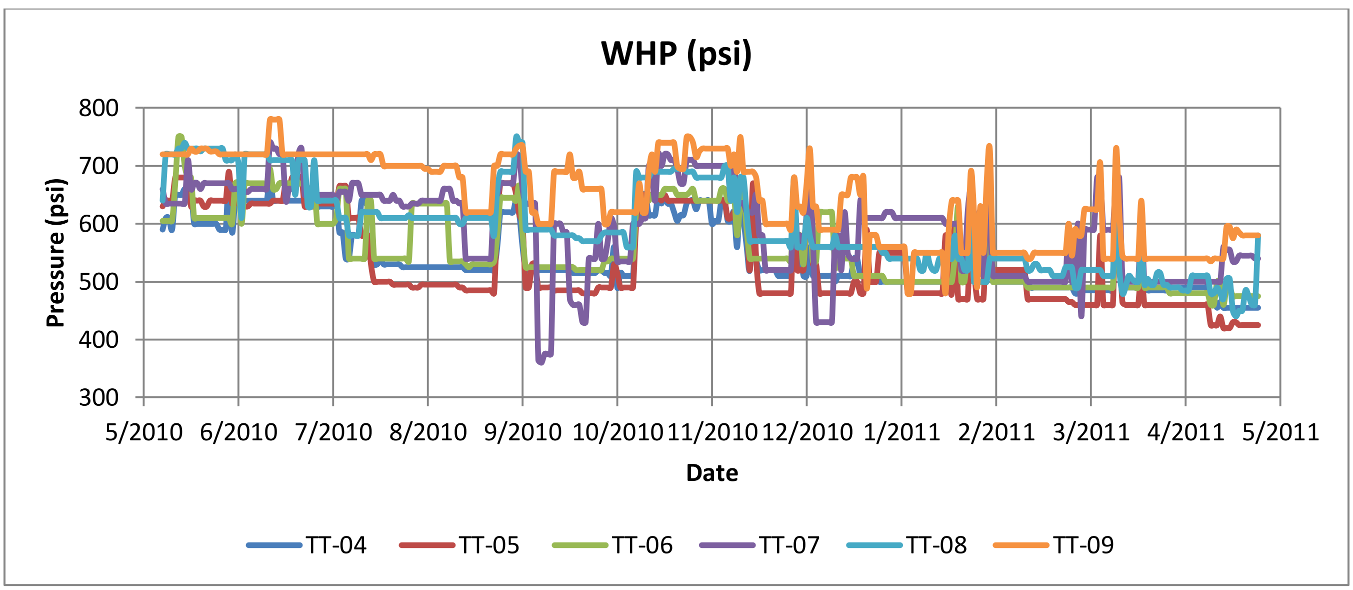


Figure 2.6 Well head pressure from May 23rd 2010 to May 5th 2011 for TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09.

The oil and gas production rates were higher in TT-04, TT-05, TT-06 and TT-09 than TT-07 and TT-09. The curves are dropped to zero values in some cases or dates not due to a rapid drop in pressure but shut in and not producing in all of the six wells for some reasons including capacity of the storage tanks, the differences in completion, chock size and reservoir characterizations like porosity and permeability of both matrix and fractures. Figure 2.7 and 2.8 are presenting the oil and gas daily production rates.

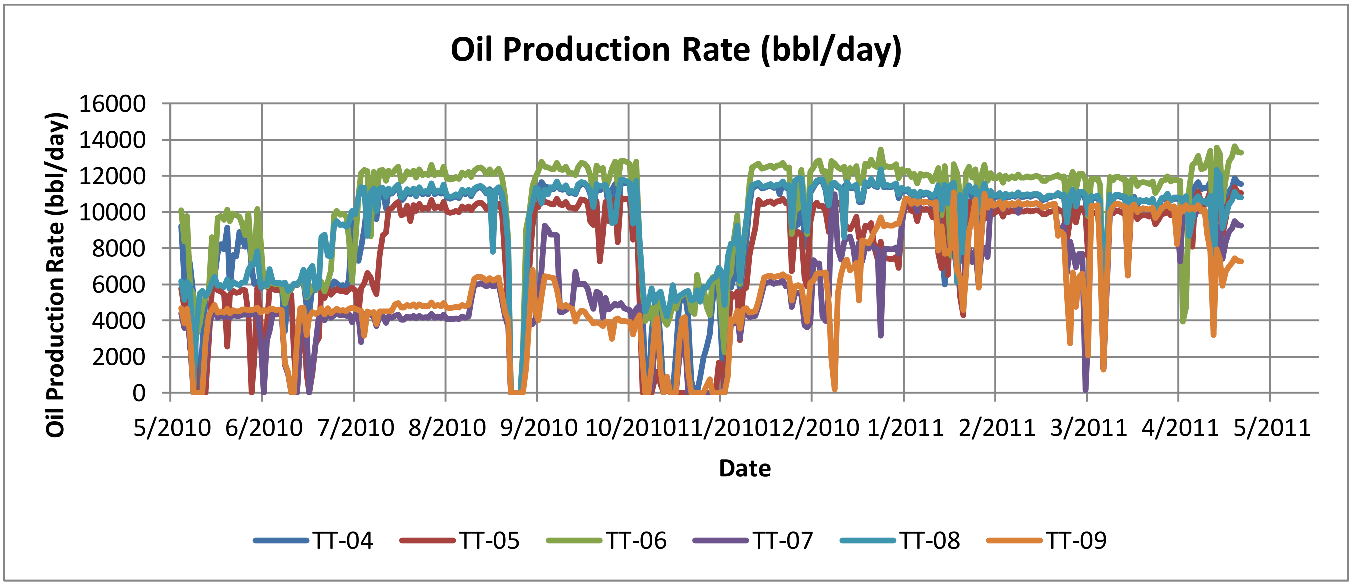


Figure 2.7 oil production rates

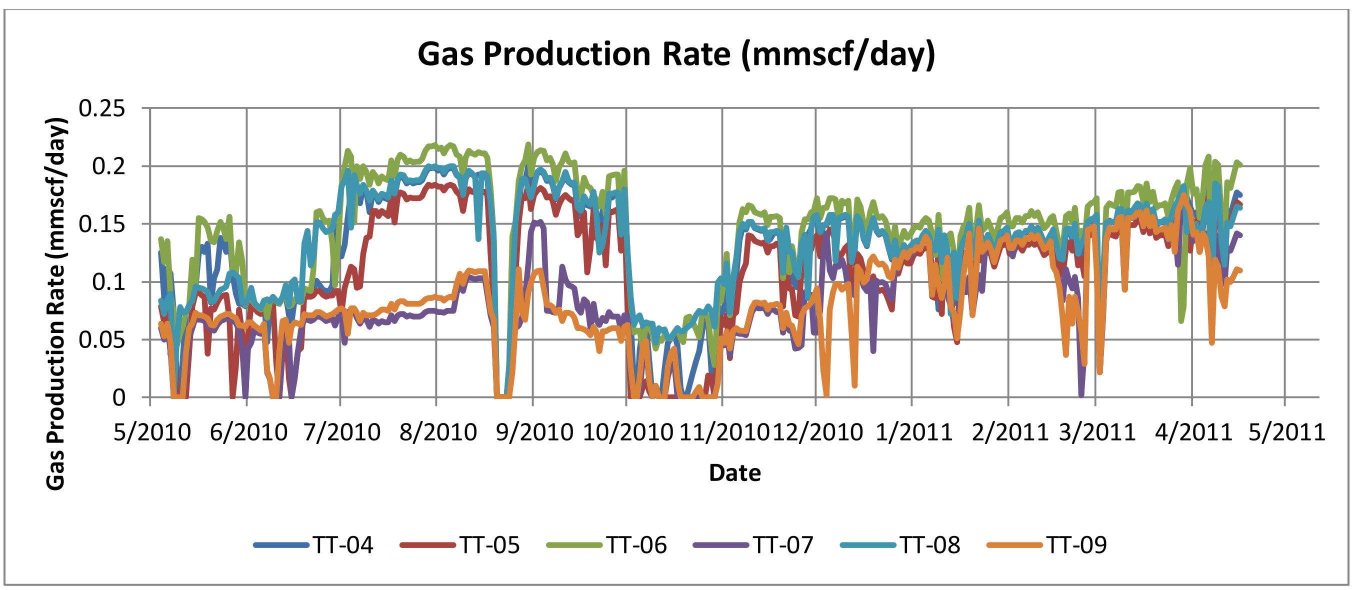


Figure 2.8 Gas production rates

Regarding the gas oil ration data, it ranges between 9 to 18 standard cubic feet per stock tank barrel (which is unusual for light oil). As stated in the production data file, the gas oil ratio has been recorded for each well at the beginning but later on only one value has been given for all the wells each day that is why the curves looks different from the beginning and as one curve later on. The only well which produced water is TT-09. The water has been started to produce from March 19th 2010. The figures 2.9 and 2.10 below are showing the gas oil ratio of the six wells and the water production rates.

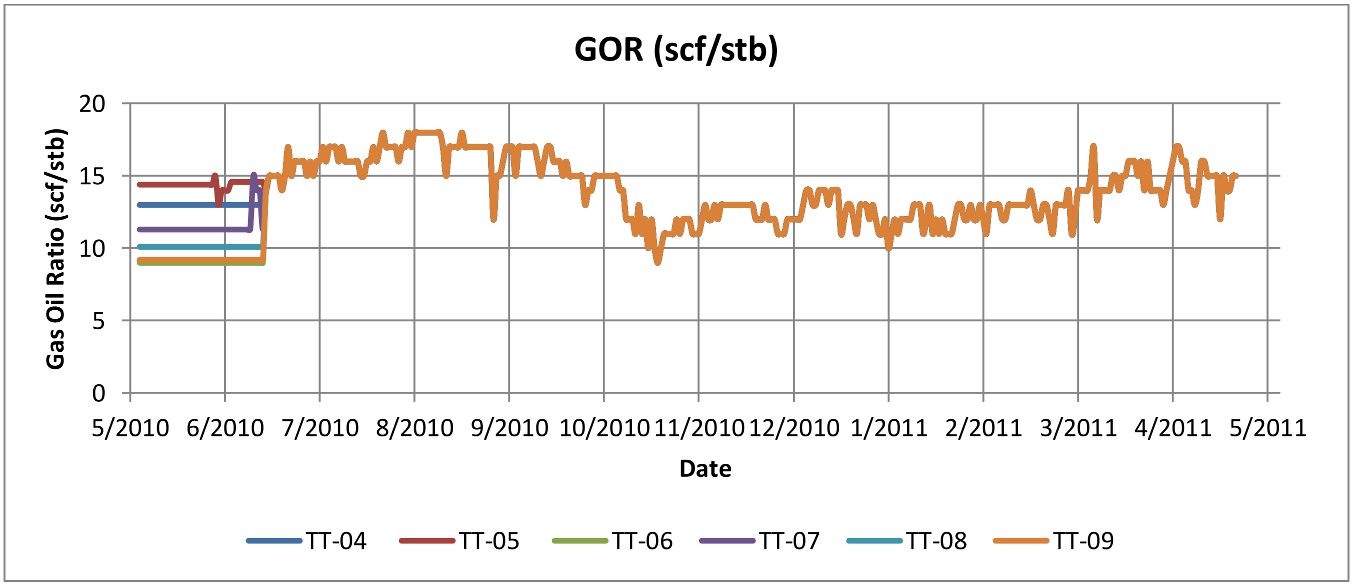


Figure 2.9 gas oil ratios

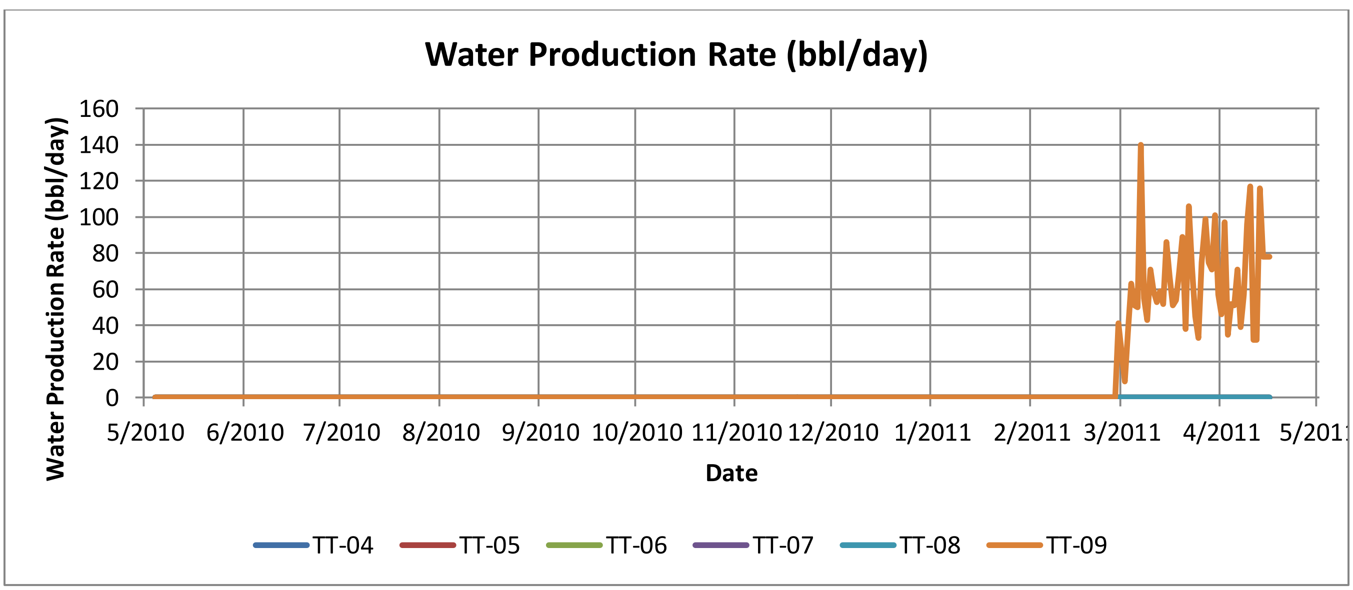


Figure 2.10 water production rates

2.3.4 Reservoir fluid data

As mentioned before, Taq Taq oil field contains two pay zones. Pilaspi formation is bearing heavy oil at about 600 meter deep and it will not be covered in this research. The second pay zone consists of Shiranish and Kometan formations which contain light oil. In the production data files, the API gravity has been recorded every day from May 23rd 2010 to May 5th 2011 for each of the six wells. The average API gravity is 48. The average reservoir temperature is about 180 degree Fahrenheit. In all of the final well reports of the six wells, the oil viscosity has been mentioned and its value is 1, 9 centipoise in Shiranish and Kometan formations. Hydrogen Sulphide has been detected also. The average gas gravity is 0, 93 gram per cubic centimeter due to the existence of carbon dioxide. In the PVT analysis report of TT-07, the oil formation volume factor is 1, 062 reservoir barrels per stock tank barrel and the oil gravity is 0, 786 gm/cc at the stock tank condition. The bubble point pressure was 149 psi. The water saturation is considered to be 25% and 5% in Kometan and Shiranish formation respectively.

2.3.5 Types of well completion

As it is obvious from the final well schemes, TT-04, TT-05 and TT-06 are cased till the bottom of the well and perforated by about 96 m and 91 m against Shiranish and Kometan formation in TT-04 respectively, 140 m and 52 m against Shiranish and Kometan formation in TT-05 respectively and 75 m and 51 m against Shiranish and Kometan formation in TT-06 respectively whereas TT-07, TT-08 and TT-09 are cased till the top of Shiranish formation and the rest of the borehole left opened. In all of the wells packers have been set at the top of Shiranish formation and at the top and bottom of Kometan formation to isolate the both mentioned formations from each other. In all of the wells production tubing has been set (till the bottom of each well) with sliding sleeves which located between the packers intervals.

3. Workflow

In this chapter the steps of the work of this research will be presented. Petrel and Eclipse have been used to make the 3D geological model of the selected reservoir and running the simulation cases to get the history match (HM). The necessary data has been provided by the Ministry of Natural Resources (MNR) of the Kurdistan Regional Government (KRG) – Iraq. It is important to mention that the data which has been given by the MNR-KRG is used as the raw material and the entire required data files that used in the software have been created from the provided data.

Petrel is the software that has been used to make the 3D geological model. In term of structural geology, simple grid model has been created which is free of geological structure like fault. The well heads, the well deviation data, the well tops, the topographic map of the upper and lower surfaces of the selected reservoir and the boundary of the studied reservoir have been used to make simple grid model. The well log data has been digitized and converted to American Standard Code for Information Interchange (ASCII) files to make property modelling like porosity and permeability. The studied reservoir composed of carbonate rocks and it was crucial to make fracture properties also. The fracture data has been digitized and converted to ASCII files to be able to use it in Petrel to make the discrete fracture network (DFN) and implicit fracture model (IFM).

Fluid modelling is coming as the next step after finishing the 3D geological model. All the fluid parameters including reservoir fluid type, properties of each fluid type, etc. have been defined in Petrel. The last step before running the simulation is importing the observed data (production data) to Petrel and making history strategy.

After the above mentioned steps, the model is ready for simulation. Petrel is providing all the required data to the simulator (for this research Eclipse 100 has been selected). Eclipse is making the calculations and visualization of the results of the simulations will be available in Petrel. The following are describing each step in more detail.

3.1 Geological part

3.1.1 The well heads

The first step of making 3D geological model in Petrel is the import of the well heads. An ASCII file should be prepared and must include the name of the wells, coordination of the wells, wells' datum value and the measured depth. Before this step the project setting must be fixed in terms of project units (Field or Metric) and coordination system. In this research unites are metric. Also the coordination system should be specified which is WGS_1984_UTM_Zone_38N. The figure 3.1 below is showing the well head file which used in this research.

TT-WELL-HEADS.txt - Notepad

File Edit Format View Help

```
# WELL HEADS
WELLS   X       Y       RT      MD
TT-04   457039  3984200 613     2286.5
TT-05   457169  3984769 613     2070.6
TT-06   454230  3987317 590     2265
TT-07   458050  3982750 555.28  2186.85
TT-08   457289  3985854 548.39  2366
TT-09   455424  3983447 522.76  24440
```

Figure 3.1 Well heads data file (ASCII format).

3.1.2 The well deviation data

After defining the location of the wells, the well paths or deviation data should be imported to Petrel. The well path data file must include the wells' name, wells' coordination and the measured depth at which the inclination and the azimuth have been taken. The deviation data file will end up with three main columns which are the measured depth, inclination and the azimuth. The well deviation data must be import to Petrel before well tops data file to avoid any mismatching between the true vertical depth and measured depth. The figure 3.2 below is showing just the header of the well deviation data file for well TT-04.

```
TT-04-DEVIATION.txt - Notepad
File  Edit  Format  View  Help
#       WELL    TRACE   FROM    PETREL
#       WELL    NAME :                  TT-04
#       WELL    HEAD    X-CO            457039
#       WELL    HEAD    Y-CO            3984200
#       WELL    RT :                    4.57
#       WELL    TYPE :                  PRODUCER
#       MD      AND     TVD     ARE     REFERENCED              (=4.57) AT      RT      AND     INCREASE        DOWNWARDS
#       ANGELS  ARE     GIVEN   IN      DEGREES
#       ANGELS  ARE     NOT     EXACT   (TRACE  WAS     NOT     IMPOTED USING   ANGLES)
MD      INCL    AZIM
47.00   0       0
61.48   0.31    37.95
67.34   0.37    65.5
76.76   0.33    42
94.87   0.74    43.41
112.44  0.77    19.71
130.12  0.78    27.6
147.95  0.69    52.72
167.28  0.54    61.43
```

Figure 3.2 TT-04 well deviation data (ASCII format)

3.1.3 The well tops

The well tops mean the intersection of the well with the top of a certain geological layer (surface). The well tops data file must include the wells' name, the name of the surfaces, the coordination of the wells and the depth of the surface (measured depth). Also the well tops data file should be in ASCII format. The figure 3.3 below is showing the well tops data file in the selected reservoir.

```
TT-WELL-TOPS.txt - Notepad
File  Edit  Format  View  Help
# WELLTOPS
WELLS   SURFACE X       Y       TOPS
TT-04   UP-SH   457039  3984200 1608
TT-04   UP-KO   457039  3984200 1857
TT-04   LO-KO   457039  3984200 1948.5
TT-05   UP-SH   457169  3984769 1630.5
TT-05   UP-KO   457169  3984769 1988
TT-05   LO-KO   457169  3984769 2070.6
TT-06   UP-SH   454230  3987317 1659
TT-06   UP-KO   454230  3987317 1957.5
TT-06   LO-KO   454230  3987317 2054.3
TT-07   UP-SH   458050  3982750 1661.5
TT-07   UP-KO   458050  3982750 1911
TT-07   LO-KO   458050  3982750 2010
TT-08   UP-SH   457289  3985854 1583.5
TT-08   UP-KO   457289  3985854 1925
TT-08   LO-KO   457289  3985854 2046
TT-09   UP-SH   455424  3983447 1635.5
TT-09   UP-KO   455424  3983447 1905
TT-09   LO-KO   455424  3983447 2001.5
```

Figure 3.3 Well tops data file (ASCII format)

3.1.4 Making surfaces

After importing the well heads, well deviation data and well tops surfaces must be created. For this step the depth contour map of upper and lower surfaces of the selected reservoir has been used. Importing images to Petrel and bring it to the real world by defining the coordination of the images' corners is possible. The figure 3.4 (appendix A1 and A2) below is showing the depth contour map of the upper and lower surfaces of the selected reservoir.

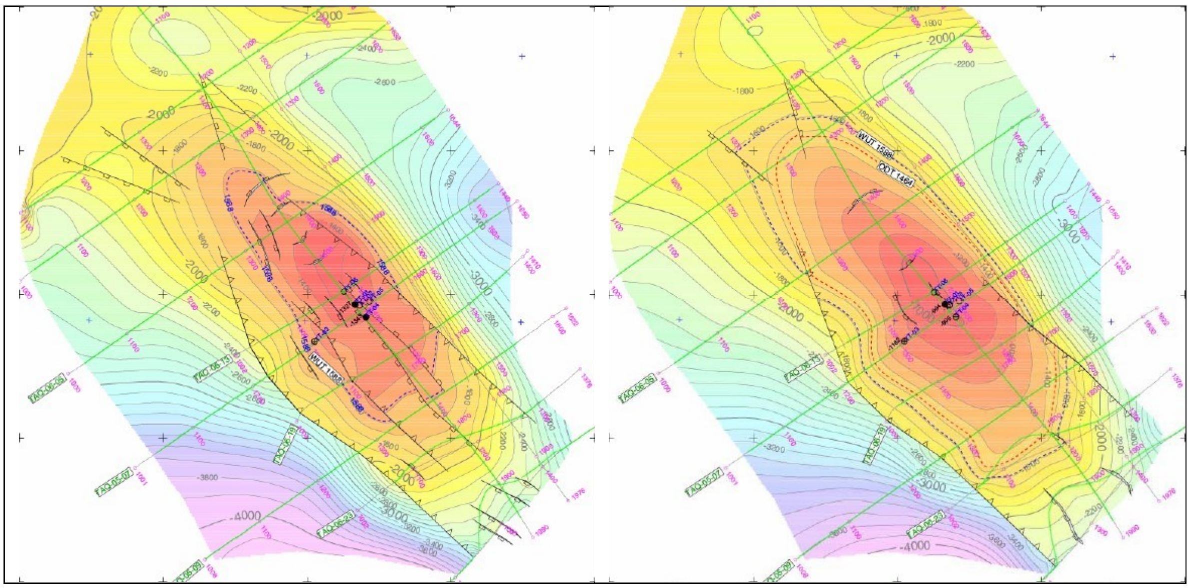


Figure 3.4 Depth contour map of upper surface (to the right) and lower surface (to the left) of the selected reservoir (MNR data).

The depth contour lines have been digitized in Petrel and polygons have been made in away that each polygon represent a certain contour line with its depth value by using Make/Edit polygon command in Petrel. Figures 3.5 (appendix A3 and A4) and 3.6 (appendix A5 and A6) are showing the digitization of the depth contour map of the upper and lower surfaces of the selected reservoir and making polygons in 2D and 3D respectively.

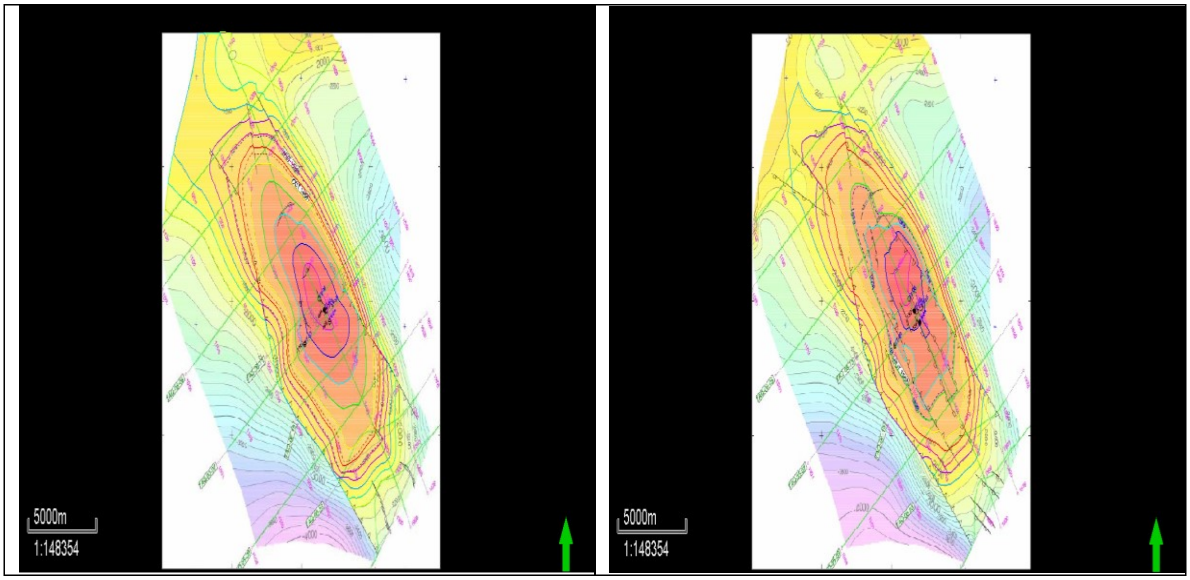


Figure 3.5 Digitization of the contour lines in 2D, the upper surface to the right and the lower surface to the left

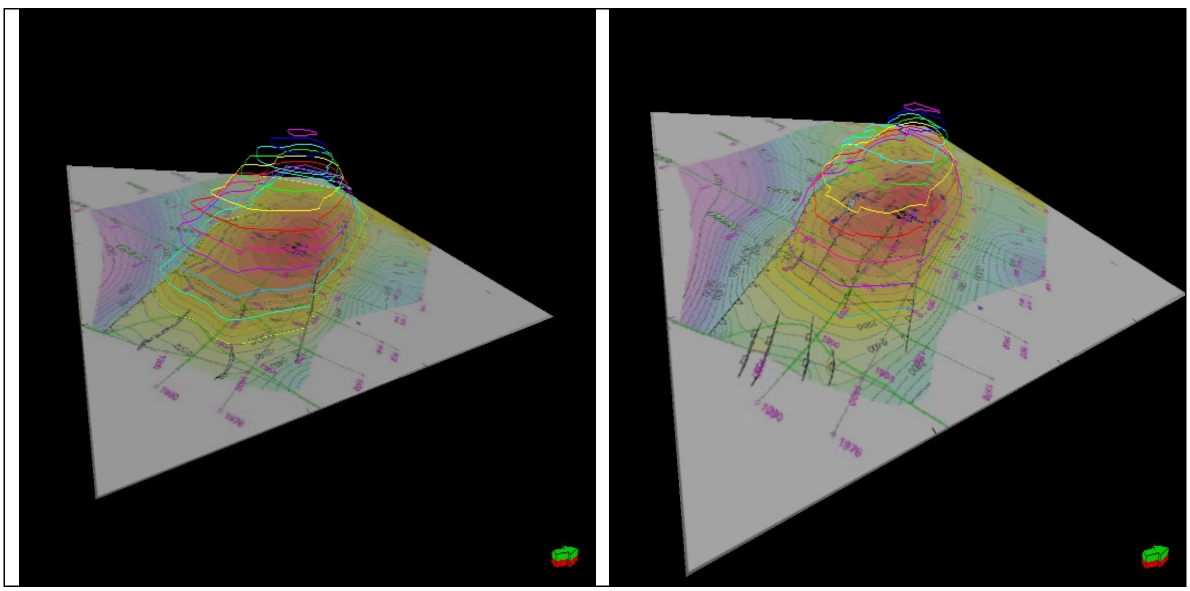


Figure 3.6 Digitization of the contour lines in 3D, the upper surface to the left and the lower surface to the right

It is important to mention that the polygons in the figures above will be used as input data with the well tops for making the upper and lower surfaces of the selected reservoir. Figure 3.7 is presenting the upper surface of the selected reservoir using the polygons and well top data. It worth to say that changing the color and style of the surface is possible in Petrel and here the depth contour map has been used as a texture (color) for the surface.

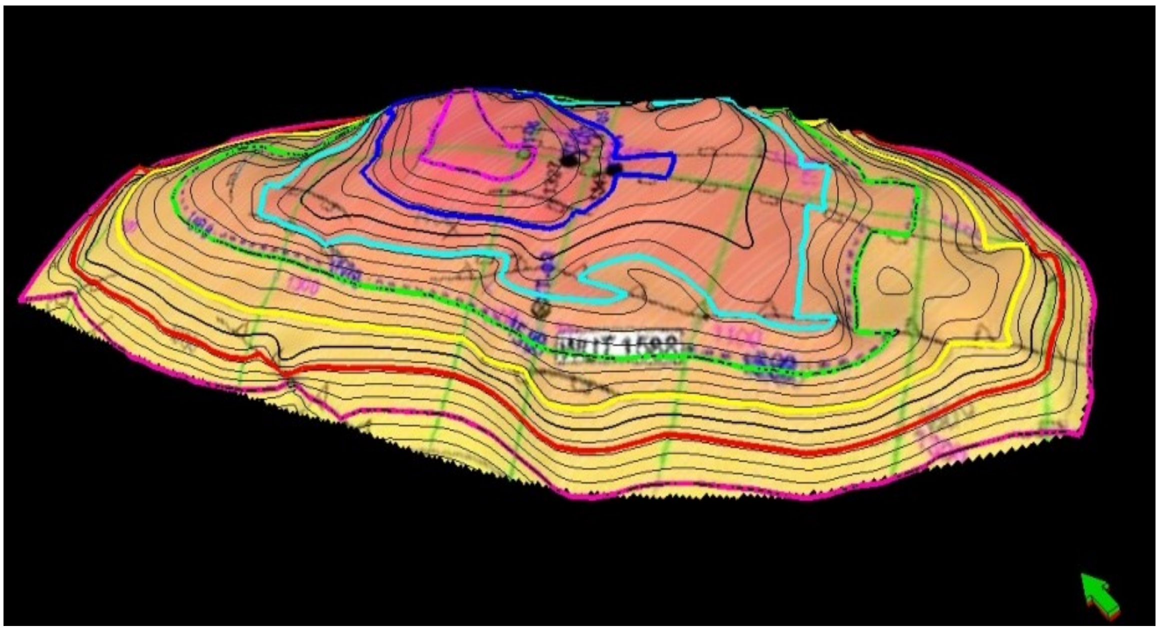


Figure 3.7 Surface has been made from the polygons and well top data and depth contour map has been used as its texture (color).

3.1.5 The boundary of the grid model

Before making surfaces, it is necessary to make the boundary of the 3D geological model. Petrel must know the dimension of the surfaces and the grid. The very most outer polygon has been selected as the boundary of the model. The selected polygon should be converted first to surface boundary and to the grid boundary later on. Figure 3.8 is presenting the boundary of the model.

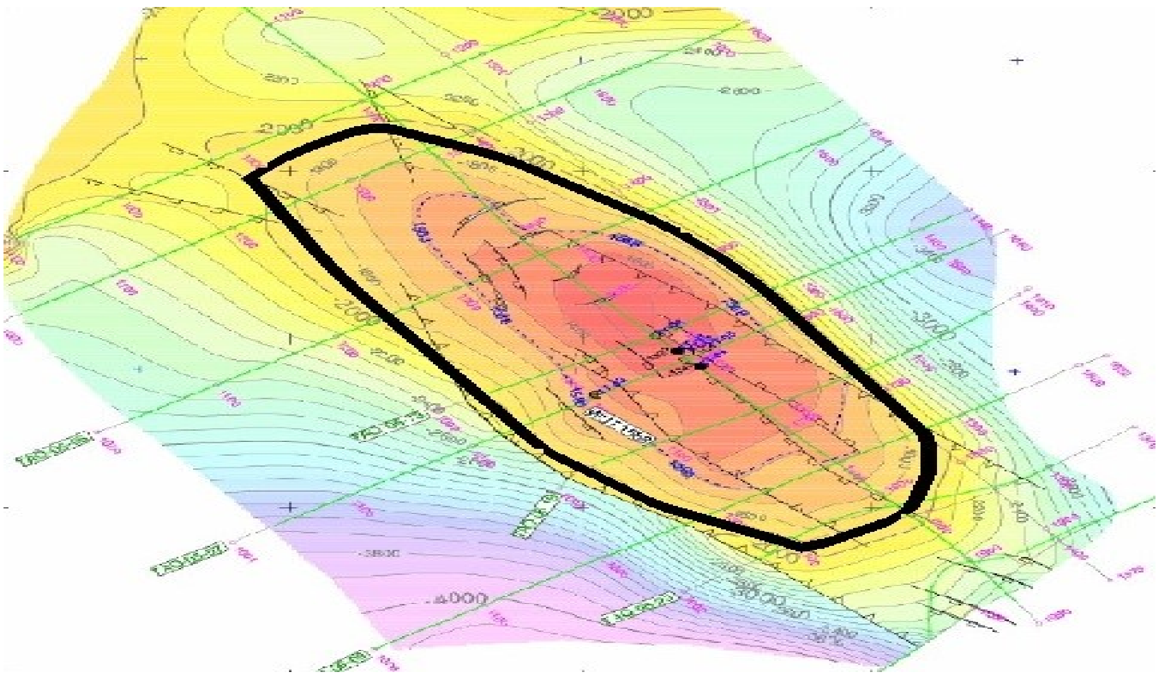


Figure 3.8 Boundary of the model (the solid black polygon).

3.1.6 Simple grid

There are three different methods in Petrel to make 3D model. The first one is called structural framework which needs seismic data and has the ability to make fault model, the second one is corner points which needs fault sticks to make the fault model and the third one is simple grid which does not contain fault model. In this research the simple grid method has been used because faults that exist in the selected reservoir have no significant role. This step requires the grid boundary and the dimension of the grid cells will be defined here. In this model the dimension of the grid cells is 50 m * 50 m. For making the 3D grid the 2D window should be active in Petrel.

Once the 3D gird is finish the horizons, the zones and the layering should be created. The surfaces that been created in the previous stages will be used here to make horizons. For this research the selected reservoir is consisting of one zone. The layering should represent the reservoir body. The well logs can tell about the different geological units that exist in the reservoir body and based on that the layering should be done. In this research the reservoir consists of 10 layers. Figure 3.9 is showing the layering and the dimension of the cells (Bulk volume property).

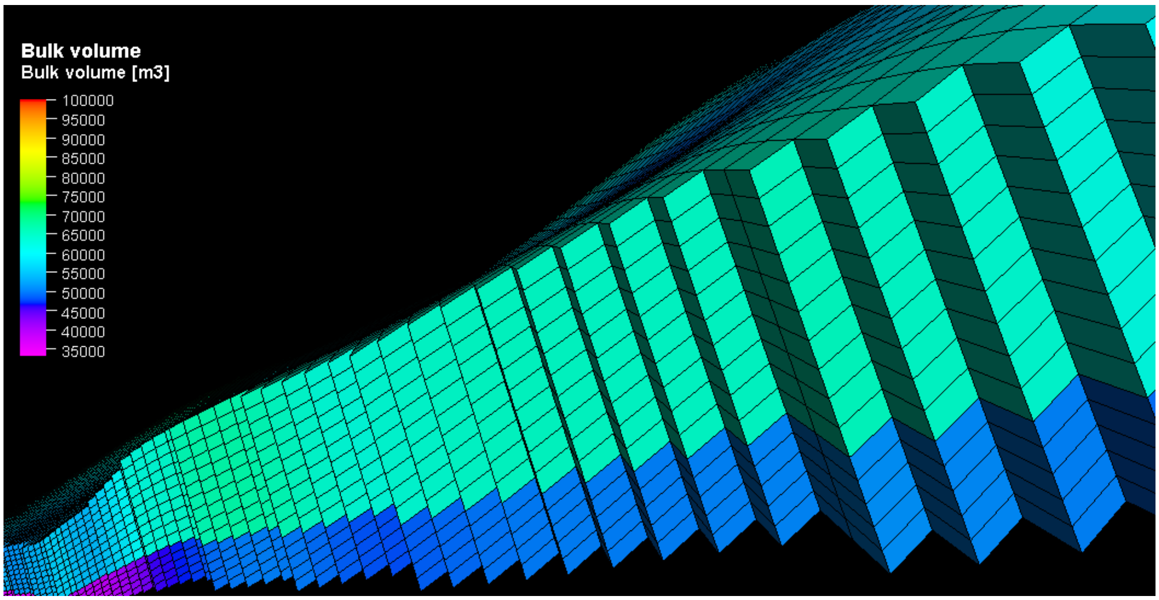


Figure 3.9 Layers and grid cells dimension.

3.1.7 Property modeling

After finishing from the construction of the reservoir body in Petrel the property modeling should be created. The most important property modeling in this research is the distribution of the natural radiation in the selected reservoir (from gamma ray log), matrix (primary) porosity (from neutron log) and matrix permeability which has been calculated by using Timur equation.

The well logs should import in to Petrel for each well and must upscale it. In the upscale process Petrel will gives a value to the cell that has been penetrated by the well. This means that if the thickness of the cell for instance is 10 m Petrel will take the arithmetic average of the well log's value in that interval and define the property value for that cell as the arithmetic average that has been calculated from the well logs values.

Once the upscale process is achieved the distribution of the property should carry out. In this stage there are several geo-statistical methods in Petrel. Selection of the distribution method depends on the quality check of the results of the distribution, for example, if the well log data, the upscale result and the distribution in the grid show harmony in the histogram then it is better to select this method as it is showing in the figure 3.10 below.

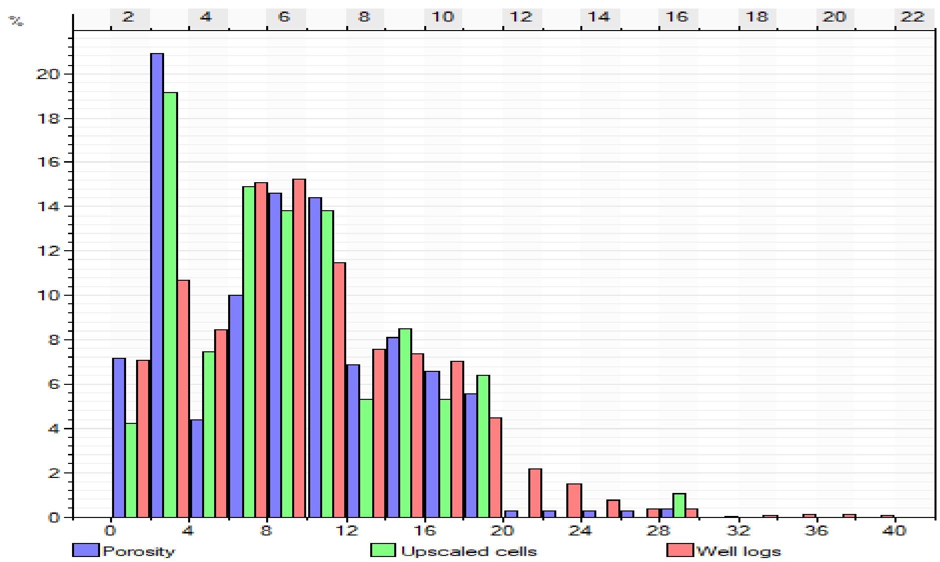


Figure 3.10 Histogram showing the harmony among the well logs, upscaled cell and the grid property (matrix porosity) distribution in the entire grid.

It is important to mention that for both porosity and permeability property modelling the Gaussian random function simulation has been used. Figure 3.11 is presenting the porosity property model for the upper layer of the selected reservoir.

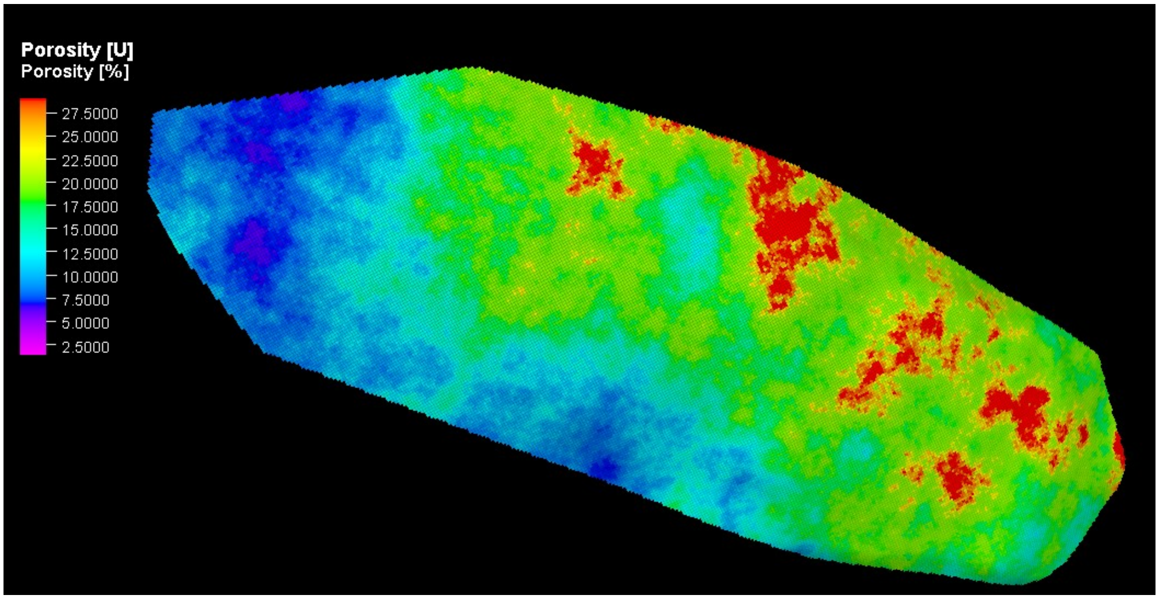


Figure 3.11 Matrix porosity distributions in the upper layer of the selected reservoir.

The same steps have been repeated to make permeability distribution. In later stages both matrix porosity and permeability in addition to the fracture porosity and permeability will be considered in the history match simulation (Dual porosity and Dual permeability). Figure 3.12 and 3.13 are showing the histogram and the permeability distribution of the selected reservoir respectively.

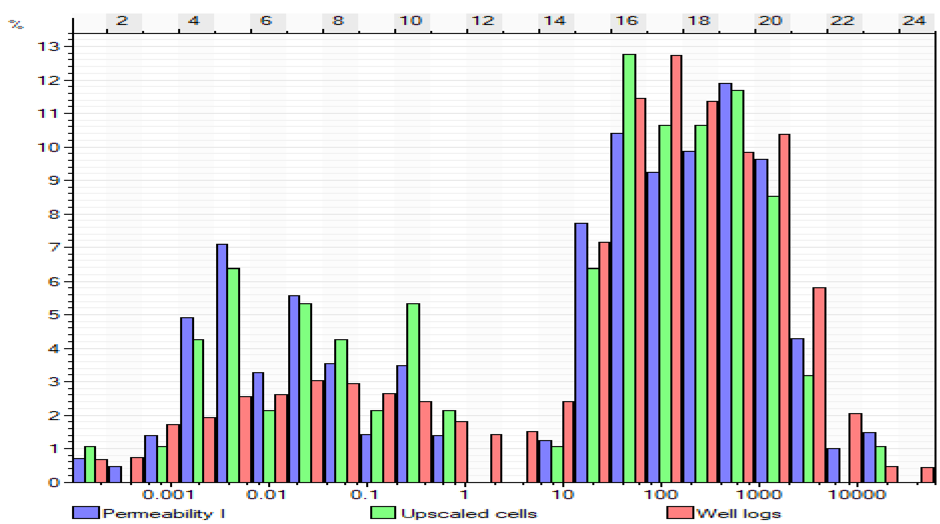


Figure 3.12 Histogram showing the harmony among the well logs, upscaled cell and the grid property (matrix permeability) distribution in the entire grid.

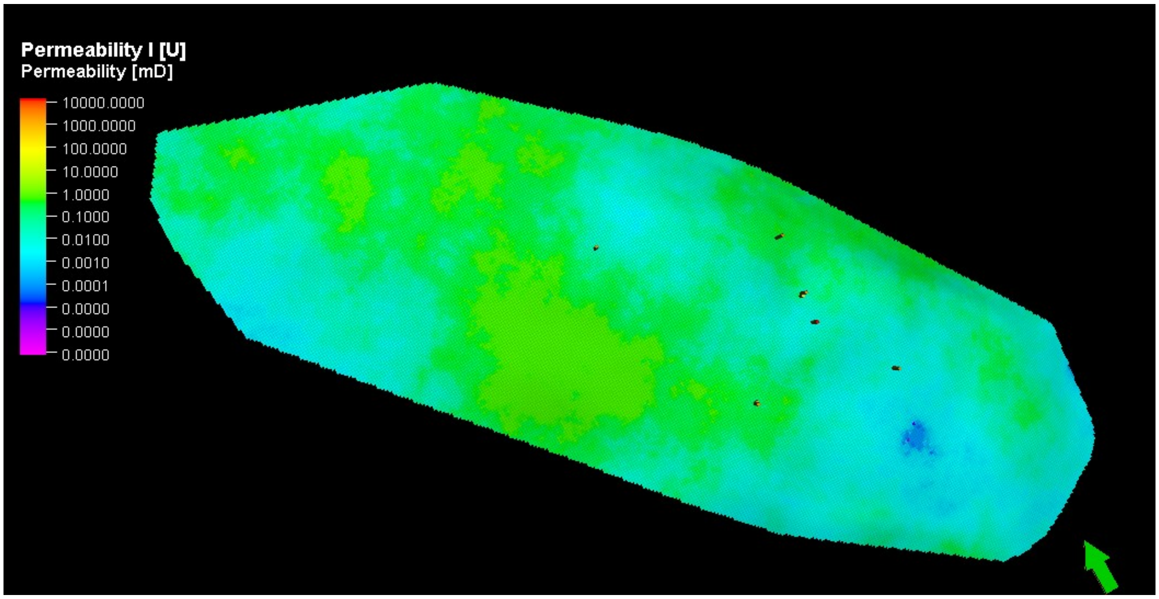


Figure 3.13 Matrix permeability distributions in the upper layer of the selected reservoir.

3.1.8 Fracture modeling

The selected reservoir consists of carbonate rock and dual porosity and dual permeability should be taking into consideration. Petrel is able to make discrete fracture network (DFN) and implicit fracture model (IFM) (as property). The difference between them is that in DFN the fracture patches are visible whereas in IFM is not and it will be presented as a property model.

To make the fracture network and later on fracture properties in Petrel the fracture data should be imported to Petrel in ASCII file format. For this purpose the formation micro imager logs FMI is needed. The fracture data file should include the name of the wells, the depth at which the measurement has been taken, the dip angle, the dip direction and the code of each fracture type. Figure 3.14 is showing the fracture data file. The fracture code is a value that tells the type of the fracture that exists in the FMI. For instance, bedding plane has a certain code also stylolite has another code different than the bedding plane code and so on.

fracture-all-ko.txt - Notepad

File Edit Format View Help

Well	MD	Dip.Ang	Dip.Azi	Code
TT-05	1988.24	267.8	62.2	1052
TT-05	1988.67	86.4	69.5	1070
TT-05	1989.19	75.6	63.9	1072
TT-05	1989.39	90.2	67.3	1082
TT-05	1989.42	332.5	6.2	1002
TT-05	1989.77	101	65.7	1072
TT-05	1990.25	187.6	8.4	1000
TT-05	1990.29	66.9	77.8	1082
TT-05	1990.39	208.8	14.5	1002
TT-05	1990.45	105.3	66.2	1072
TT-05	1991	77	63.2	1082
TT-05	1991.17	86.3	63.1	1072
TT-05	1991.36	116	65.6	1072
TT-05	1991.43	219.5	3.2	1002

Figure 3.14 the fracture data file.

After importing the fracture data file to Petrel the tadpoles should be created. This is very helpful regarding the visualization and interpretation of the fracture data. Each color and each shape of the tadpoles are representing a certain type of fracture. Plotting of the Rose diagram beside the tadpoles is also possible and it gives an idea about the orientation of the fractures. One of the requirements for making DFN is intensity log which can be created from fracture data file. The figure 3.15 below is showing the tadpoles, rose diagram and the intensity log in one well for the selected reservoir interval.

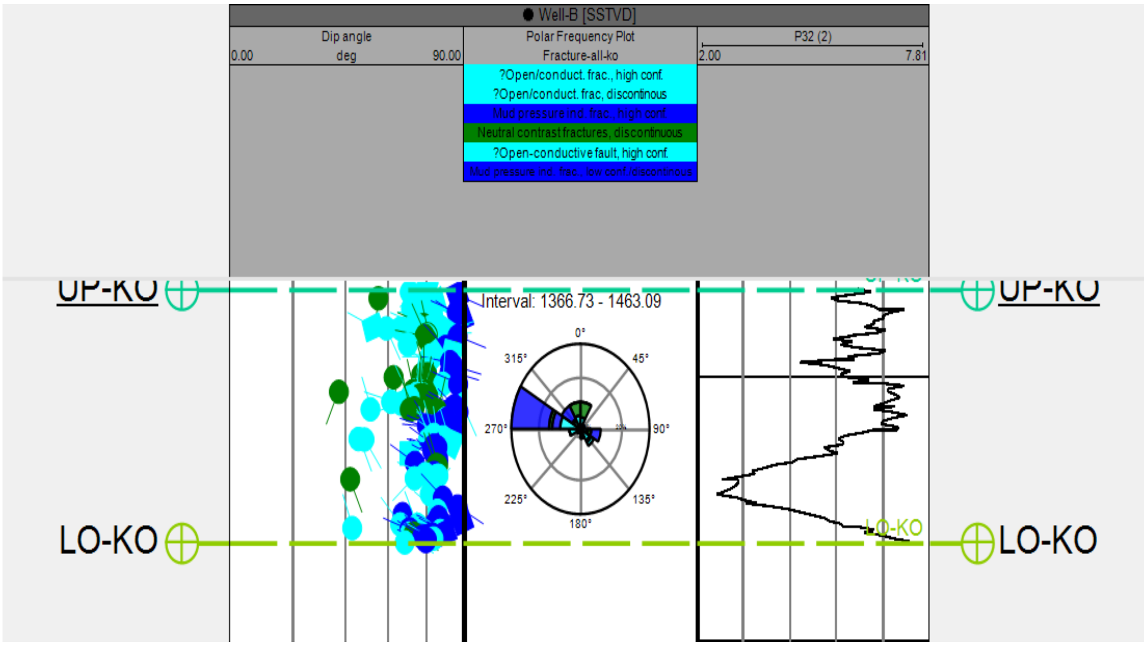


Figure 3.15 Tadpoles, Rose diagram and Intensity log.

Fracture intensity log should be upscaled and distribute it as a property. A geo-statistical method must be used to make the distribution and by default the Gaussian random function simulation has been used. Figure 3.16 is showing the fracture intensity distribution.

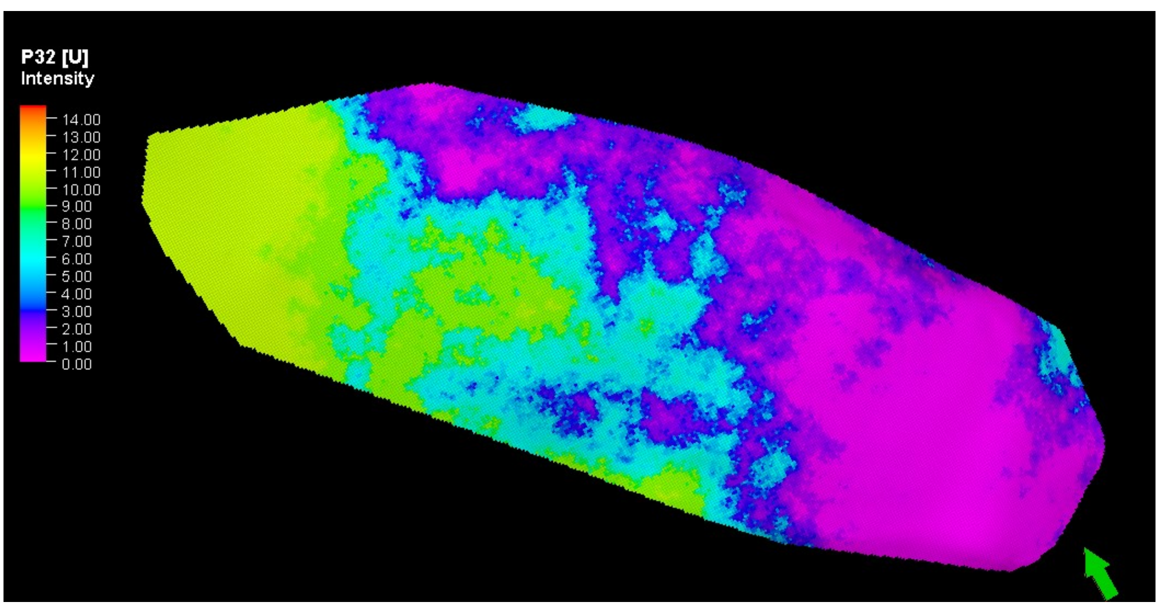


Figure 3.16 The fracture intensity distribution.

The next step after making the fracture intensity distribution is the discrete fracture network and implicit fracture model. In Petrel there are three geo-statistical methods for making the DFN and IFM. Fisher, Kent and Bingham are the three methods that can be used for the fracture network distribution. Fisher distribution is the default method in Petrel and it has been used in this research also. The figure 3.17 below is the DFN distribution using Fisher distribution model. It is important to say that the patches' color represent the different patches' direction.

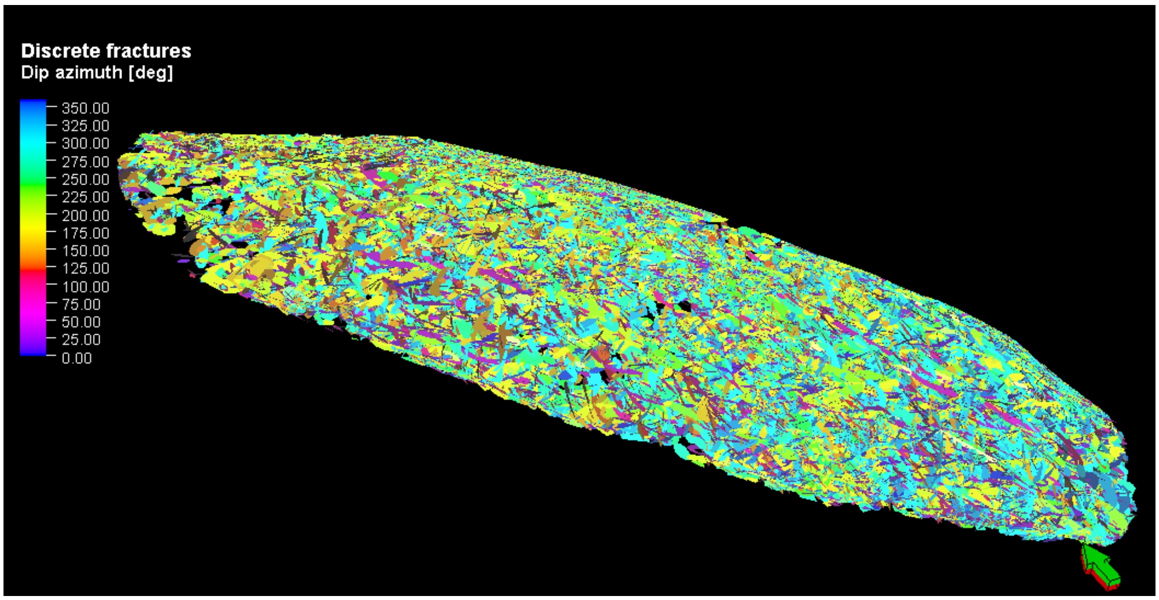


Figure 3.17 The DFN using Fisher distribution model.

As mentioned before in the DFN the fracture patches are visible and their length can be determined during the fracture modelling or more precisely the maximum and the minimum length of the visible fracture paths can be determined whereas the fractures that their lengths are less the minimum length (which will be determined by the user) of the fracture that have been determined in the DFN model will be modeled as the IFM and distribute as property. The figure 3.18 below is showing the IFM.

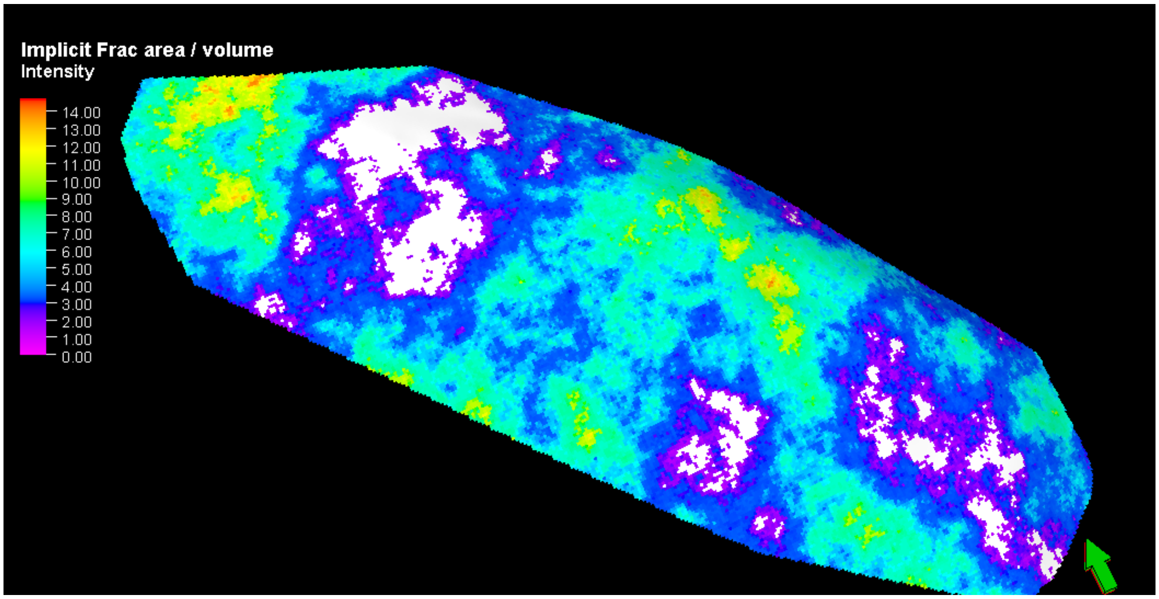


Figure 3.18 The IFM (total fracture/volume).

After finishing the DFN and IFM, Petrel is ready to make the fracture properties including the fracture porosity and the fracture permeability. Petrel also make sigma factor which can be defined the factor or parameter that shows the connection between the matrix properties (matrix porosity and matrix permeability) and the fracture properties (fracture porosity and fracture permeability). It is important to mention that Petrel will make fracture permeability in I.J and K directions. Figure 3.19, 3.20 and 3.21 are showing the fracture porosity, fracture permeability and sigma factor respectively.

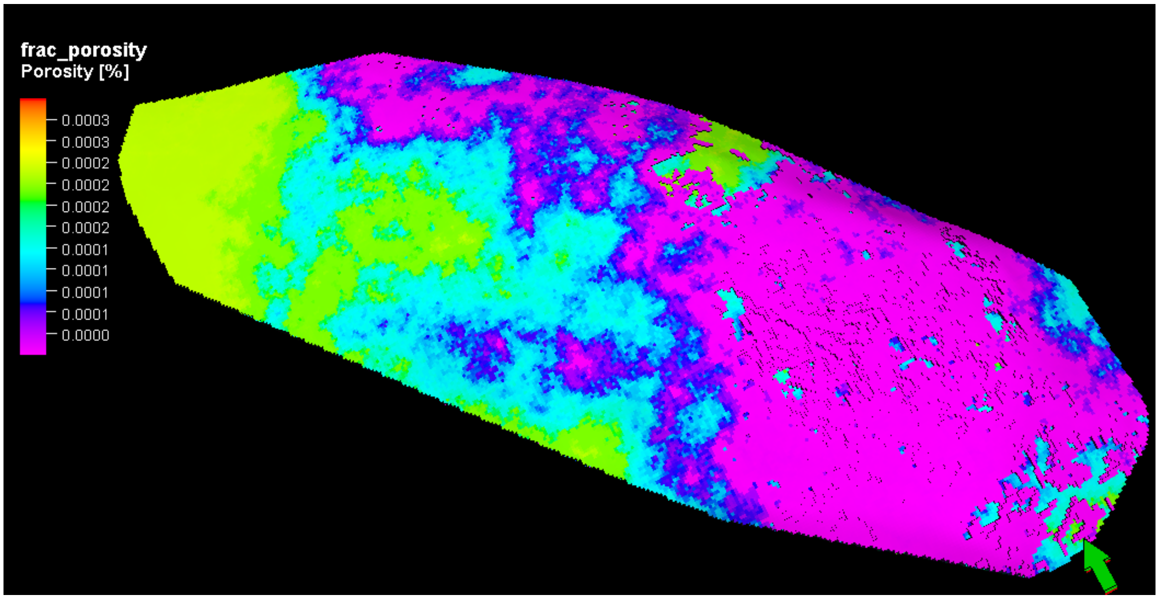


Figure 3.19 The fracture porosity.

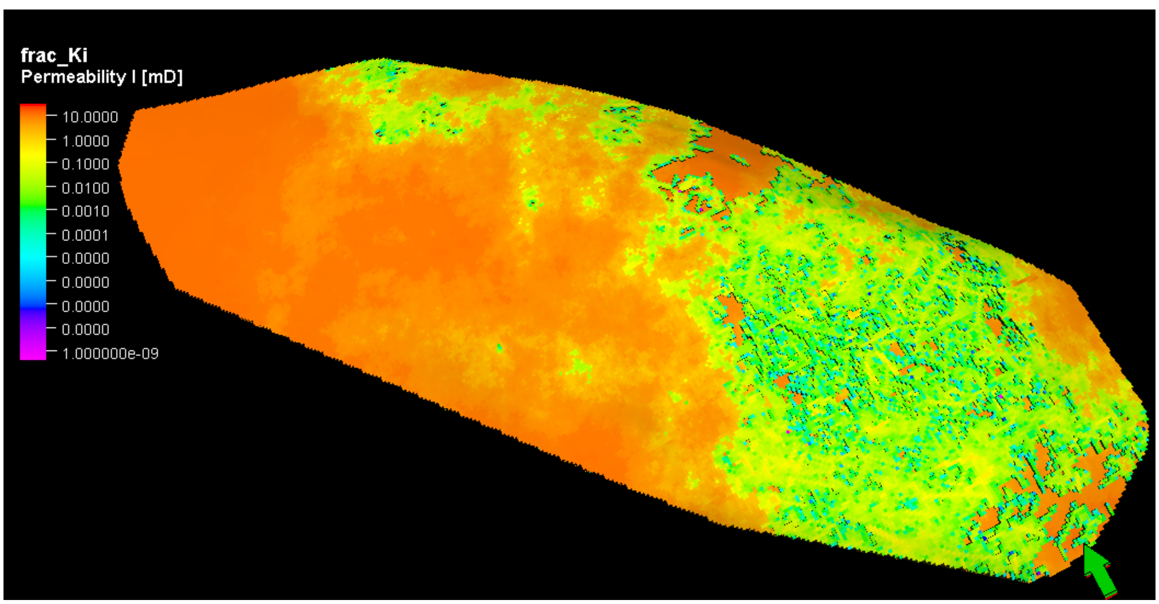


Figure 3.20 The fracture permeability.

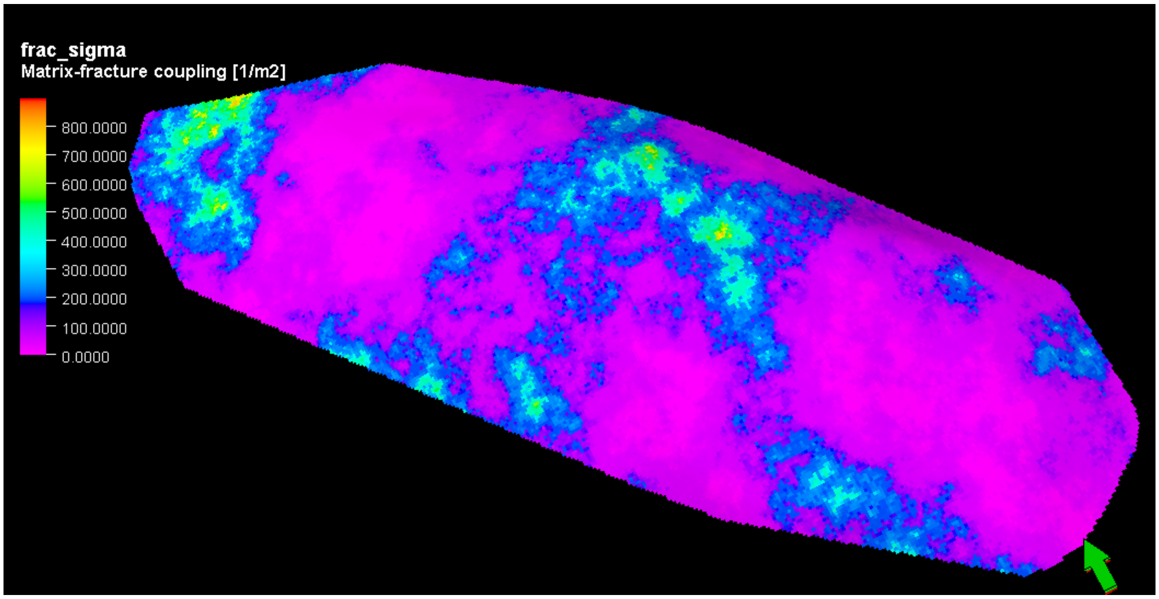


Figure 3.21 The sigma factor.

A mathematical relationship has been proposed by (Kazemi H. et al 1976) to express the dual porosity dual permeability matrix – fracture coupling. The mentioned relationship has been used by Petrel to make the sigma factor property distribution. The equation below is showing Kazemi's relationship.

$$\sigma = 4 * \left(\frac{1}{l_x^2} + \frac{1}{l_y^2} + \frac{1}{l_z^2}\right)$$

Where *lx, ly* and *lz* are typical X, Y and Z dimensions of the matrix blocks.

It is worthy to say that the first stage of the model is finished. Clearly speaking, after making the fracture properties the 3D geological model is ready to take the reservoir engineering data and been prepared to run the simulation by using Eclipse. In the following pages the model preparation for the simulation will be discussed. It includes the import of the production data, making fluid model, making history strategy, defining the reservoir parameters, running the simulation and visualizing the results in Petrel.

3.2 Reservoir engineering part

3.2.1 Fluid modeling

Fluid model is another step that should be made before running the simulation. In this step the reservoir fluid should be determined in addition to the properties of each component of the reservoir fluid model. The very first component of the fluid model to be specified is the reservoir fluid model type. This can be black oil or compositional or thermal depending on what fluids are exist in the reservoir. Each model type has user preset which allow the user to determine the model type or more precisely for example in black oil model type the user can determine whether the reservoir fluid composed mainly of dry gas or light oil and gas or heavy oil and gas or dead oil. Black oil model has been created in this research because the fluid type of the selected reservoir is mainly light oil with very low gas oil ratio (almost dead oil) and the production data include gas, oil and water.

In the general tab the phases that exist in the reservoir should be toggled on like gas, oil and water in addition to the separator and reservoir conditions like separator temperature and pressure and reservoir temperature and pressure. In the gas tab the gas properties should be specified like vaporized oil gas ratio, gas gravity and gas density. In the oil tab the following parameters should be determined including oil density, oil gravity, solution gas oil ratio and bubble point pressure. It is important to mention that in Petrel it is possible to determine a certain method or use the software default in making the correlations. For instance, the user can rely on the default correlation method regarding the bubble point pressure (for example) which will be one of the following methods depending on the input data like Al – Marhoun 1988, Al – Shammasi 1999, Farshad & Leblanc 1992, Glaso 1980, Kartoatmodjo & Schmidt 1994, Labedi 1990, Lasater 1958, Petrosky & Farshad 1993, Standing 1947, Valko & McCain 2003, Vasquez & Beggs 1980, Velarade, Blasingame & McCain 1999.

Regarding the reservoir water properties, the following parameters must be determined including the water salinity, water density, water viscosity, water formation volume factor, compressibility, and viscosibility. Also here is possible to use the software default correlation or using the user defined correlation regarding the formation volume factor, the compressibility and the water viscosity. For example, the user can use the default correlation method regarding the formation volume factor (which depend on the input data) or specify a certain correlation method like McCain 1990, Meehan 1980, Meehan 1980 no gas and HP – 41 Fluid Pac.

The last stage in making the fluid model is the determination of the reservoir initial conditions. The parameters that should be defined here are the pressure, the datum depth, the oil - water contact depth and the capillary pressure.

3.2.2 Rock physics

In the rock physics section there are other parameters that should be specified. Saturation is one of the parameters that should be defined including the gas saturation, oil saturation and water saturation. Based on that the software is making relative permeability functions like oil-water, gas-oil and gas-water relative permeability functions in addition to the gas-oil, oil-water and gas-water capillary pressure functions.

Another parameter that must be determined here is the rock compaction function. It is also important to define the reservoir rock type in this section too whether it is consolidate or unconsolidated sandstone or limestone.

3.2.3 Observed data

Before running the simulation, the observed production data should be imported to Petrel. It is important to mention that the observed data file is an ASCII data file but the extension of the data file should be .VOL. The observed data file should include name of the wells, data of production and/or injection, the production rates of gas, oil and water, the injection rates of water if any, water cut and the bottom hole pressure. Figure 3.22 is showing the observed data file.

```
OBSERVED.vol - Notepad
File   Edit   Format   View   Help
*FIELD
*MONTHLY
*IGNORE_MISSING
*UPTIME_FRACTIONS
*UUCRATES
*MONTH   *YEAR   *WINJ   *GAS     *OIL    *WATER   *WCT
*NAME RTD-1
1        2003    0       293665   4196    5258     0
2        2003    0       240006   2859    6534     0
3        2003    0       213326   3954    11484    0
4        2003    0       387687   1994    8716     0
5        2003    0       288936   970     8505     0
6        2003    0       207631   823     8876     0
7        2003    0       356996   1070    9780     0
8        2003    0       320778   907     7204     0
9        2003    0       291443   1018    10498    0
10       2003    0       351768   1143    12330    0
11       2003    0       429336   1521    13862    0
12       2003    0       411829   1618    13176    0
1        2004    0       379696   1359    12408    0
2        2004    0       211031   3389    11160    0
```

Figure 3.22 Observed data file.

3.2.4 Making history strategy

In this part, the strategy will be defined. There are two main types of strategy. The first one is the history match strategy and the second one is for the prediction. In the history strategy the user is defining the history matching period according to the date of the observed data for instance the starting and the ending date of production and/or injection. Also the producer and the injector wells will be defined.

Another parameter that should be selected here is the type the simulator. Petrel is able to be connected to several simulators like Eclipse 100, Eclipse 300, FrontSim and INTERSECT. In this research Eclipse 100 has been used. Another important parameter which must be defined here is the rules. In this part the user is setting the procedure that the software should follow to make the history strategy like specifying the period whether it is daily, monthly or yearly. History rate control is another rule that should be defined here. It is important to set the production control mode to the reservoir volume and specifying the wells that contribute to the simulation and also the observed data set because sometime it is possible to have more than one observed data set.

3.2.5 Defining the simulation case

This section is the last part before clicking the RUN button. In this section the user is creating a case and it is better to have a certain name because later on after modification in some parts of the model there will be another case with a different name to be run and later on be able to compare the results of the cases with the observed data. In this section the user is also defining the simulation type whether it is a single porosity, dual porosity or dual permeability. In this research dual permeability has been selected because of the selected reservoir which composed of carbonate rocks.

In the grid tab the user will define the dual porosity and dual permeability parameters. In the functions tab the drainage relative permeability, the rock compaction (which have been created in the rock physics part) and the black oil fluid model (which has been created in the fluid model part) will be defined. In the strategies tab the strategy will be defined whether it is history strategy or prediction strategy.

In the result tab the user is able to define the items that match the research interest to be visualized like field, group, wells, oil, water, gas, rates, ratios etc. and not all the items in the result tab are necessary for every simulation case. In the advanced tab there is a very important button which is the “Editor”. By clicking on this button the user will be able to access the Eclipse sections and play with the sections by adding and removing keywords.

Now everything is finished and the model is ready for the simulation and the only remaining thing here is pushing the RUN button. Petrel is allowing Eclipse to access all the necessary information to make the simulation. After finishing the simulation the user is able to visualize the results in Petrel.

To sum up, in this chapter the most necessary steps for making a 3D geological model for the selected reservoir in addition to the fluid model, rock physics, observed data, making strategy and defining simulation case are carried out. Another aim of this chapter is to give the reader an idea about the stages that have been done to achieve this work by the researcher. Table 7 shows the model parameters.

Table 3.1 Reservoir model: the table shows the reservoir model properties, fluid model properties and the initialization parameters.

Matrix porosity	1.5 – 29 %	Fracture porosity	$6.15*10^{-15}$ – 0.0003
Matrix permeability	0 – 13500 md (I,J) 8975 md (K)	Fracture permeability	$4.2*10^{-10}$ – 31 md (I) $1.2*10^{-10}$ – 48 md (J) $3.2*10^{-13}$ – 33 md (K)
Rock compressibility	0.00004735 bar^{-1}	Matrix-Fracture connectivity	0 – 897 $1/m^2$
Properties of the fluid model			
API gravity	48°	Gas oil ratio	8.25 m^3/m^3 (M1) 2.74 m^3/m^3 (M2)
Oil viscosity	0.68 – 0.76 cp (M1) 1.4 – 1.6 cp (M2)	Formation volume factor – oil	1.09 – 1.11 rm^3/m^3 (M1) 1 – 1.01 rm^3/m^3 (M2)
Oil density	0.787 gm/cm^3	Bubble point pressure	10 bar (M1) 4 bar (M2)
Initialization parameters and the model dimensions			
Oil saturation	0.8	Oil water contact	-1588 m
Water saturation	0.2	Model dimensions	About 18500 m length About 6100m width About 400 m thick
Reservoir pressure	215 bar	Number and dimensions of the grid cells	595245 cell 50 m*50 m*27 m

(M1) denotes to the fluid model which used in Case-Bp-10-10

(M2) denotes to the fluid model which used in Case-Bp-04-04

4. Results

4.1 History matching

4.1.1 Oil production rates

According to the observed production data, it is very clear that the production in Taq Taq oil field until 05.05.2011 was only from TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09. The history match has been conducted for the period from 23.05.2010 till 05.05.2011 (348 days). Figure 4.1 shows the location of the six wells which their production data have been used in this research for the above mentioned period.

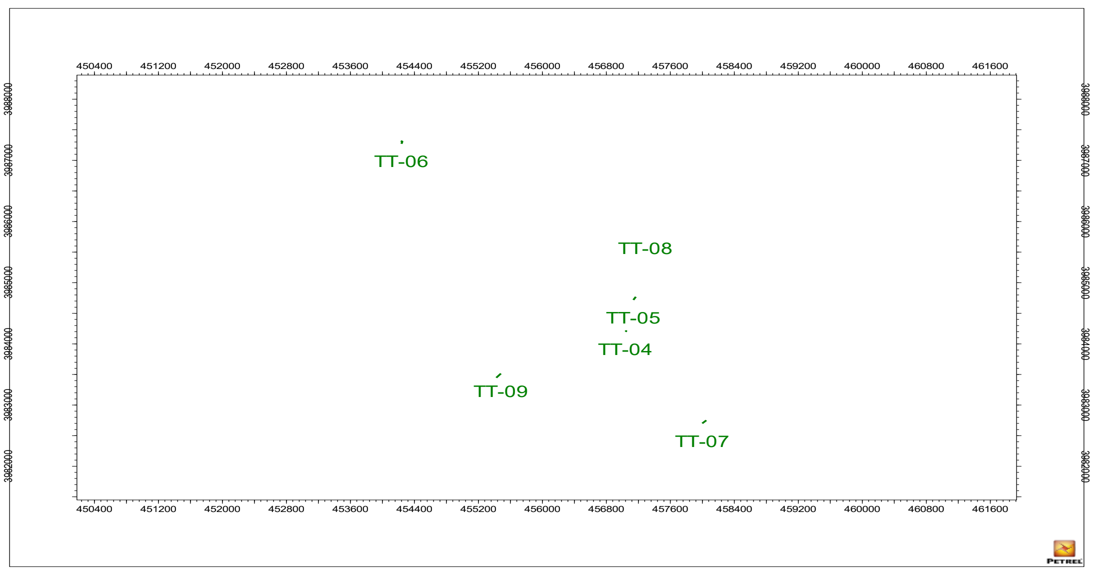


Figure 4.1 location of the wells at the early development stages of Taq Taq oil field

It is important to mention that the three dimensional geological model reacted to the history matching process positively. The matching case for the oil production rate for the six wells and also for the total field oil rate has been achieved straightforwardly due to the excellent construction of the geological model. Several history matching cases have been run and only two of them are presented here. In both cases the oil production rate shows very good matching. The figures below show the oil rate matching for the wells TT-04, TT-05, TT-06, TT-07, TT-08, TT-09 and all of them together.

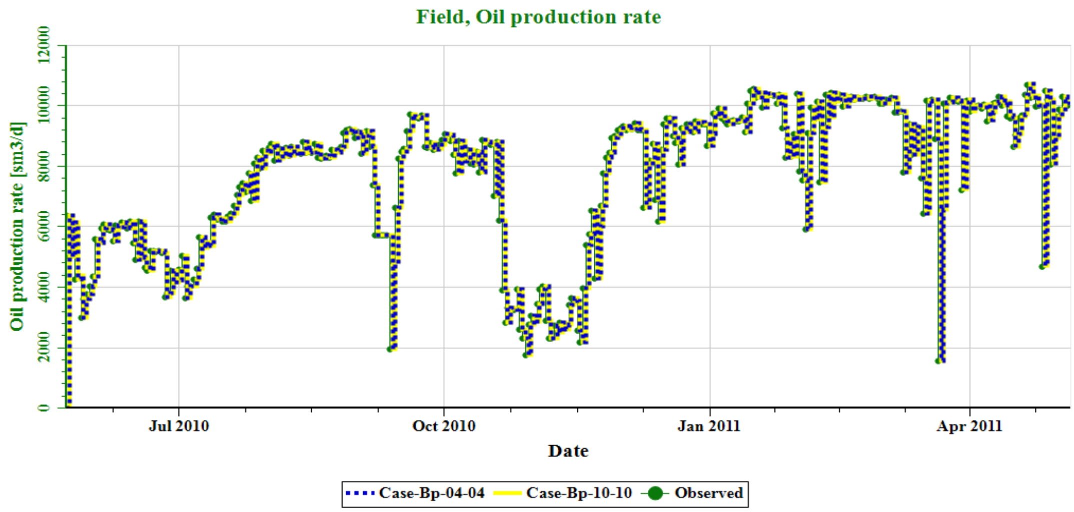


Figure 4.2 Results of the history match (Oil-Field)

The figure above 4.2 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producers (the total field oil production rate)

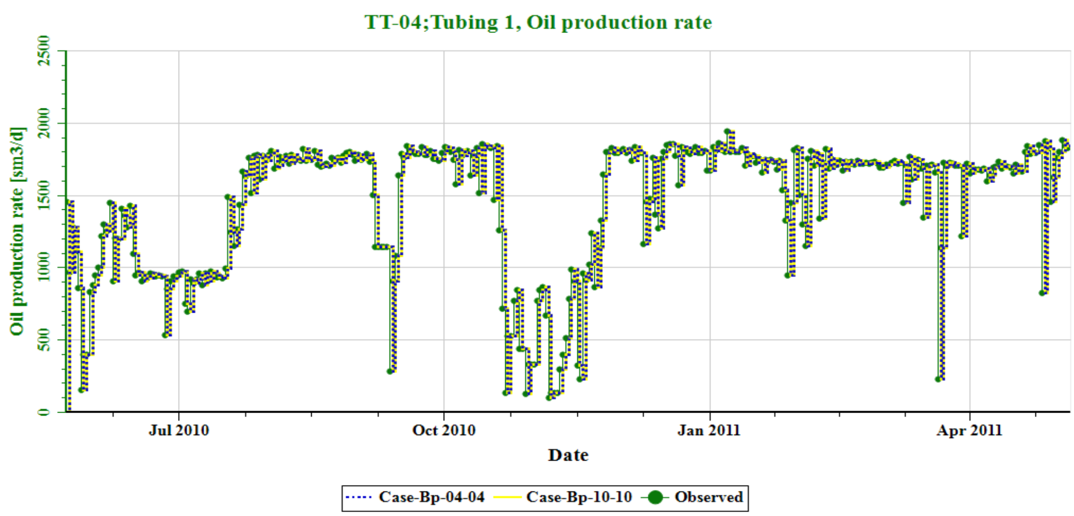


Figure 4.3 Results of the history match (Oil-TT-04)

The figure above 4.3 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-04

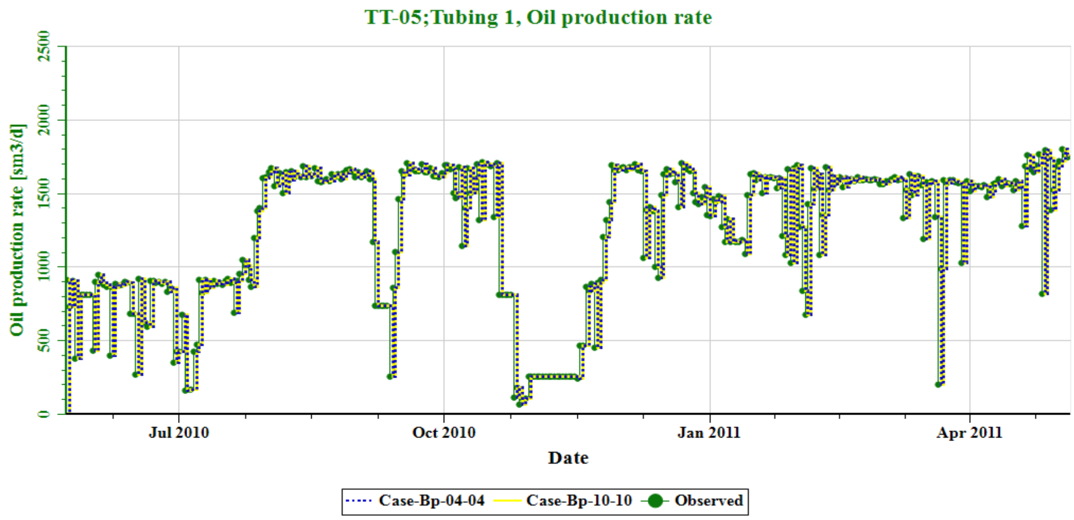


Figure 4.4 Results of the history match (Oil-TT-05)

The figure above 4.4 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-05

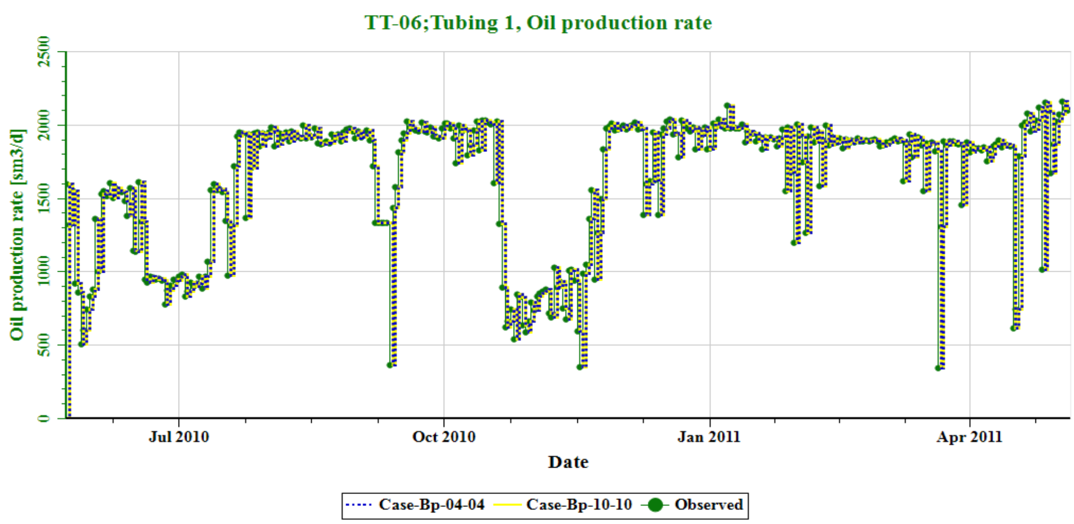


Figure 4.5 Results of the history match (Oil-TT-06)

The figure above 4.5 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-06

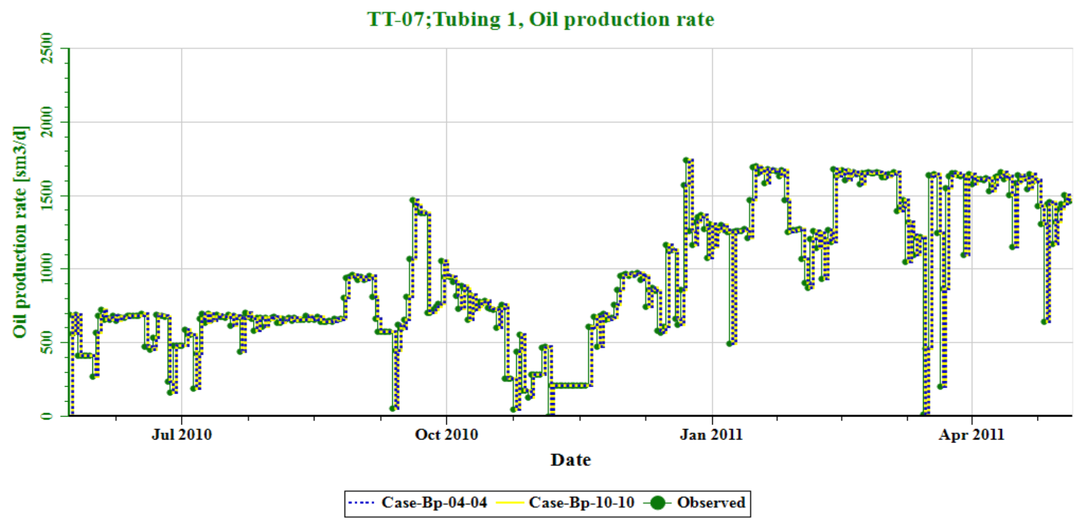


Figure 4.6 Results of the history match (Oil-TT-07)

The figure above 4.6 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-07

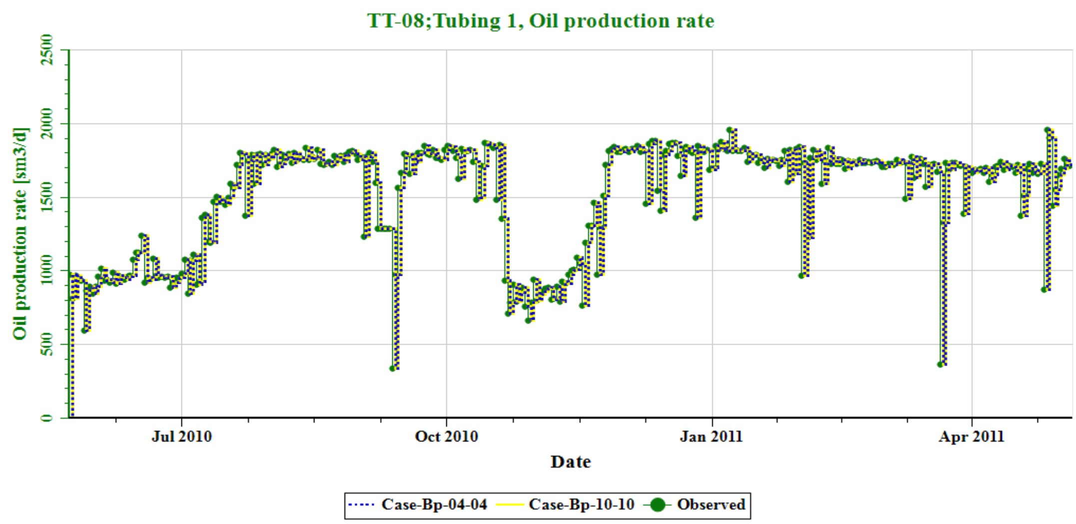


Figure 4.7 Results of the history match (Oil-TT-08)

The figure above 4.7 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-08

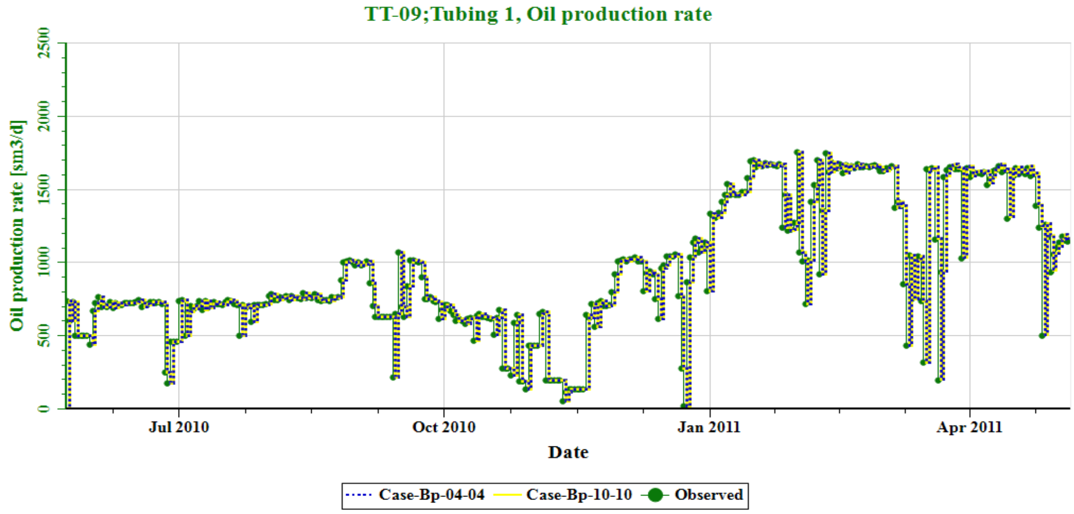


Figure 4.8 Results of the history match (Oil-TT-09)

The figure above 4.8 is presenting the comparison between the observed date (green line with filled green circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the yellow solid line) for the oil production rate of the producer TT-09

4.1.2 Gas production rates

As mentioned before, several simulation cases have been run and only two of them are presented here. Both of the cases are showing very good matching regarding the oil production rates whereas for the gas production rate it is not the case. All the parameters have been given to defining the simulation case as it is mentioned in the data report which the result was Case-Bp-10-10. Here the bubble point pressure was 10 bars which led to produce bigger gas rate in comparison to the observed gas production data. From the production data spreadsheet which has been given by the Ministry of Natural Resources of Kurdistan regional government – Iraq, the gas oil ratio is about 16 scf/stb. The bubble point pressure has been reduced to 4 bars and the case re-ran again and the result showed better matching as presented below. The new case called Case-Bp-04-04.

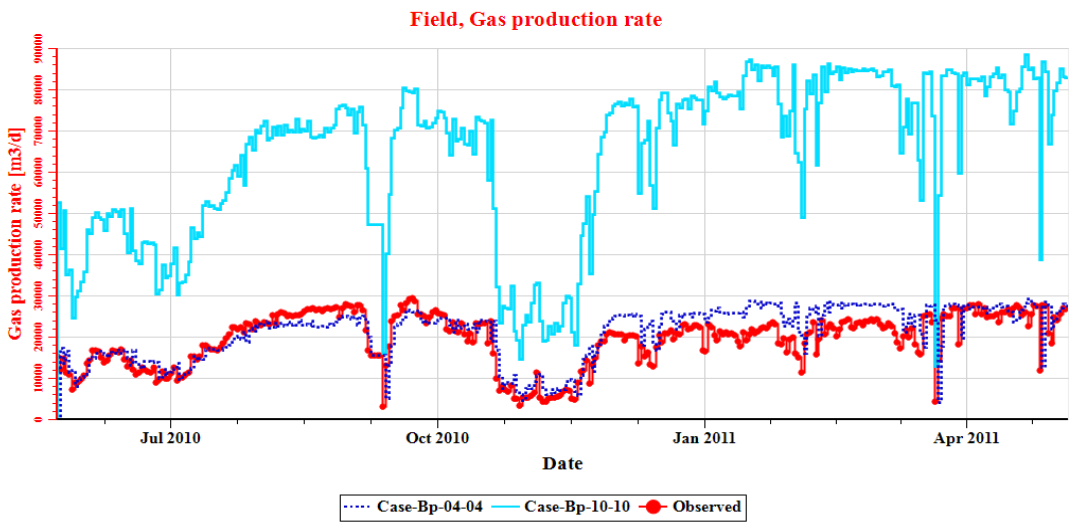


Figure 4.9 Results of the history match (Gas-Field)

The figure above 4.9 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producers (the total field gas production rate)

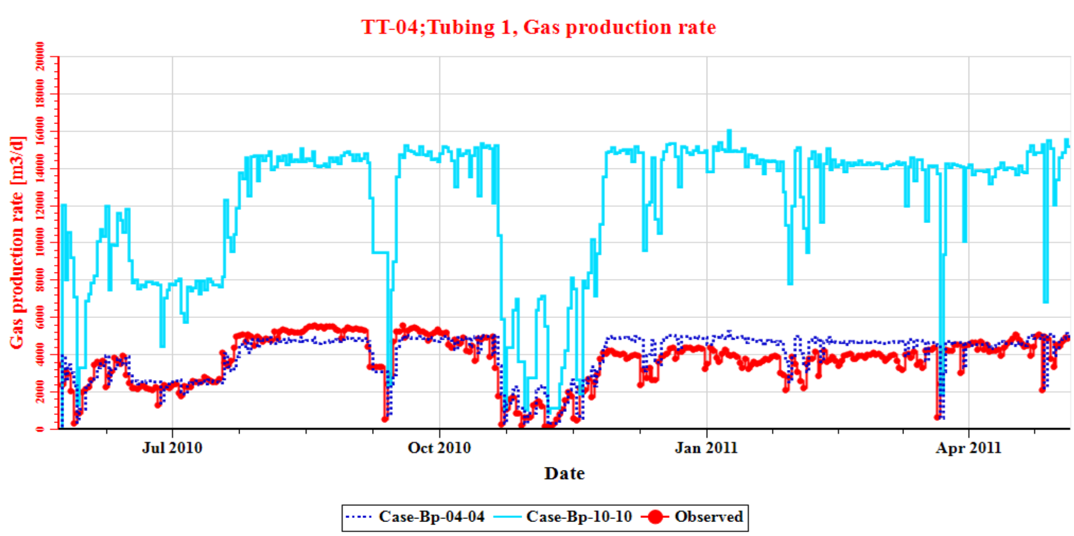


Figure 4.10 Results of the history match (Gas-TT-04)

The figure above 4.10 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-04

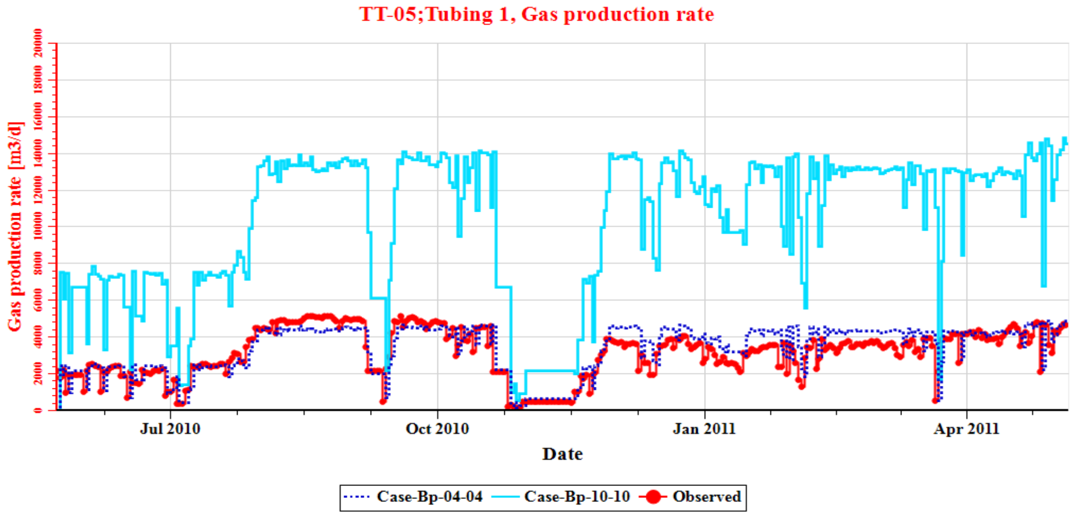


Figure 4.11 Results of the history match (Gas-TT-05)

The figure above 4.11 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-05

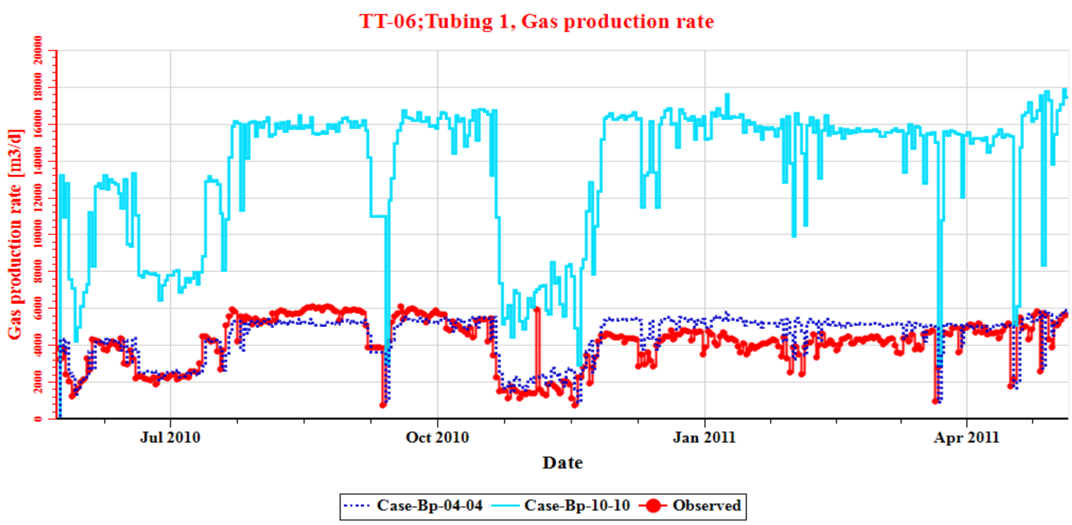


Figure 4.12 Results of the history match (Gas-TT-06)

The figure above 4.12 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-06

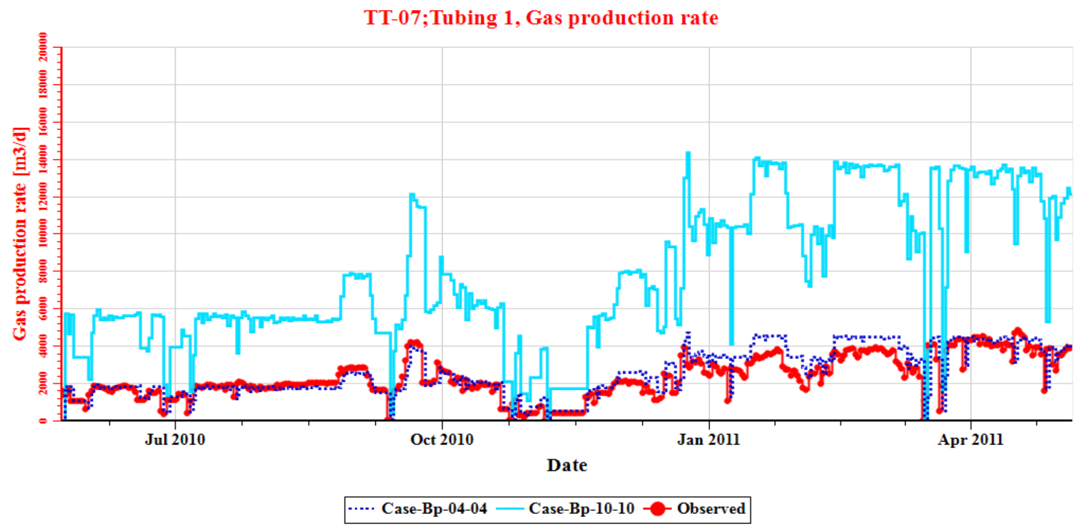


Figure 4.13 Results of the history match (Gas-TT-07)

The figure above 4.13 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-07

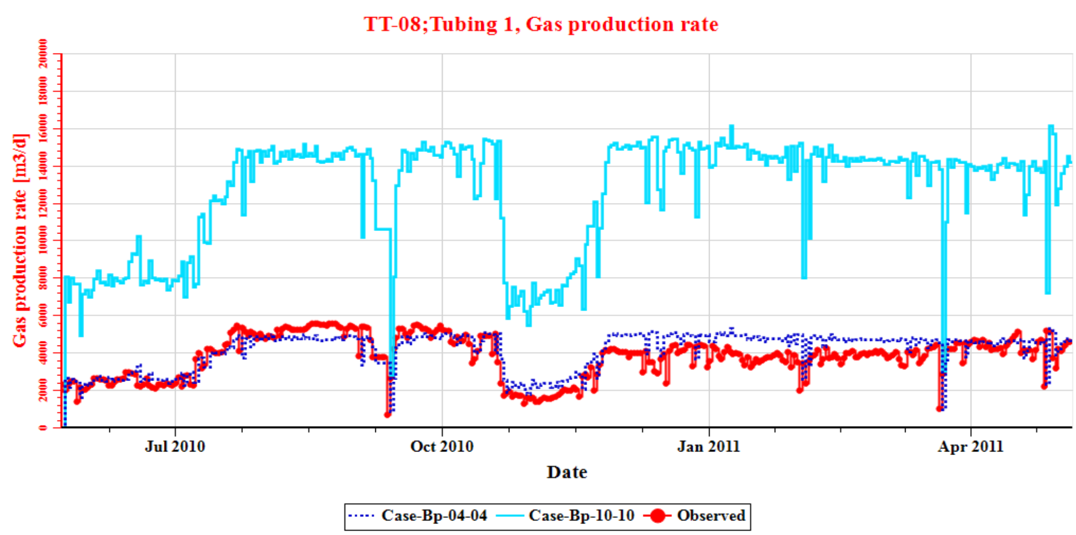


Figure 4.14 Results of the history match (Gas-TT-08)

The figure above 4.14 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-08

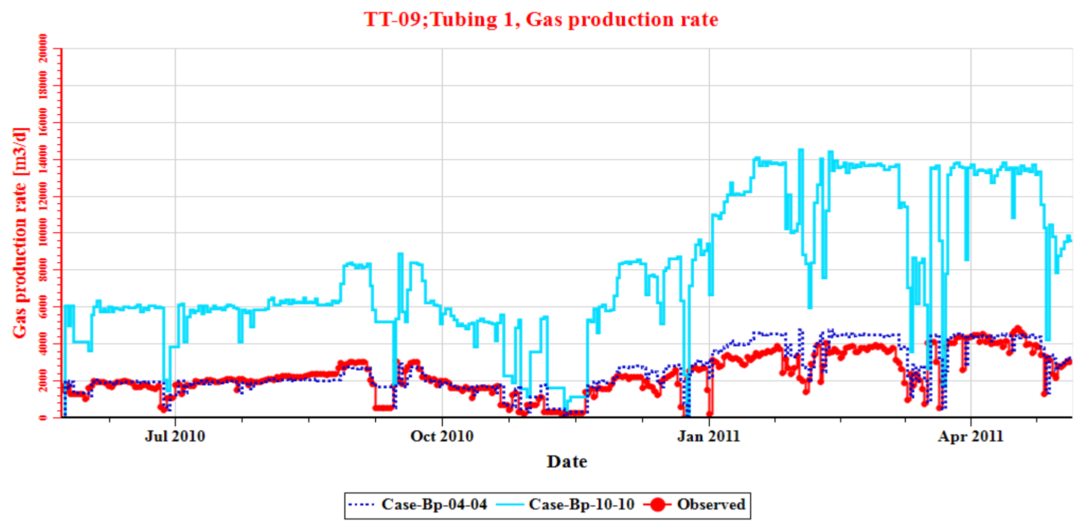


Figure 4.15 Results of the history match (Gas-TT-09)

The figure above 4.15 is presenting the comparison between the observed date (red line with filled red circle), simulation Case-Bp-04-04 (blue dotted line) and simulation Case-Bp-10-10 (the light blue solid line) for the gas production rate of the producer TT-09

4.1.3 Well head and bottom hole pressure

The history matching cases comprised also the wellhead and bottom hole pressure and Case-Bp-04-04 shows better matching than Case-Bp-10-10. In order to get wellhead pressure simulation case, vertical flow performance for each well in Petrel must be carried out. Regarding the bottom hole pressure data, it was not available directly from the data reports. Hagedorn – Brown correlation has been used to obtain the bottom hole pressure from the wellhead pressure and other required data for this purpose. The figures below displaying the matched and miss-matched cases for both wellhead and bottom hole pressure for TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09.

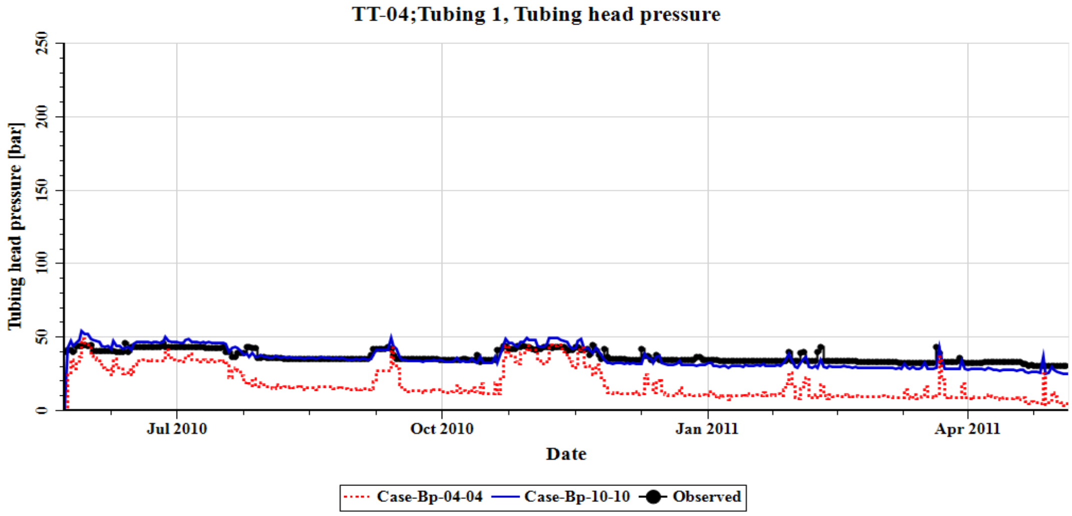


Figure 4.16 Results of the history match (WHP-TT-04)

The figure above 4.16 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-04

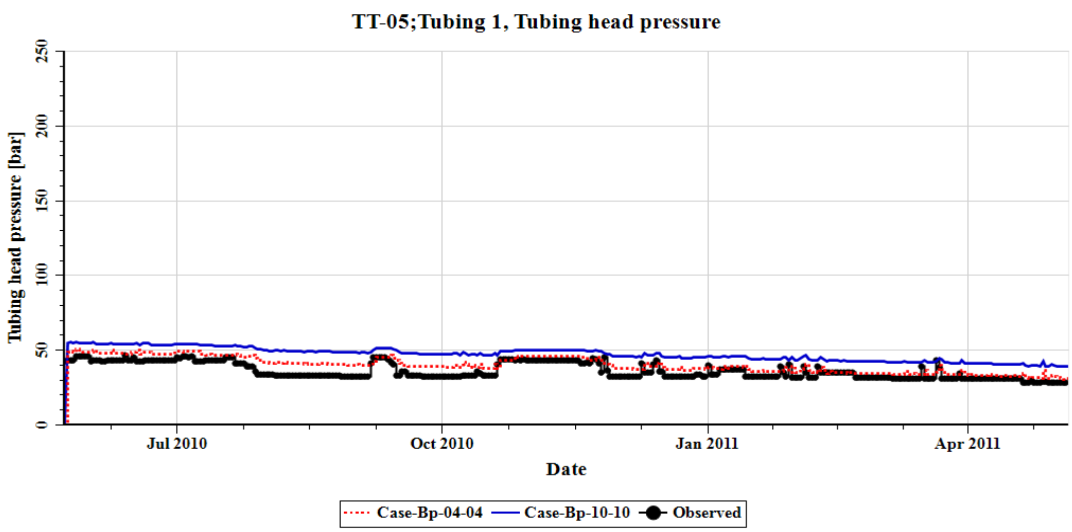


Figure 4.17 Results of the history match (WHP-TT-05)

The figure above 4.17 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-05

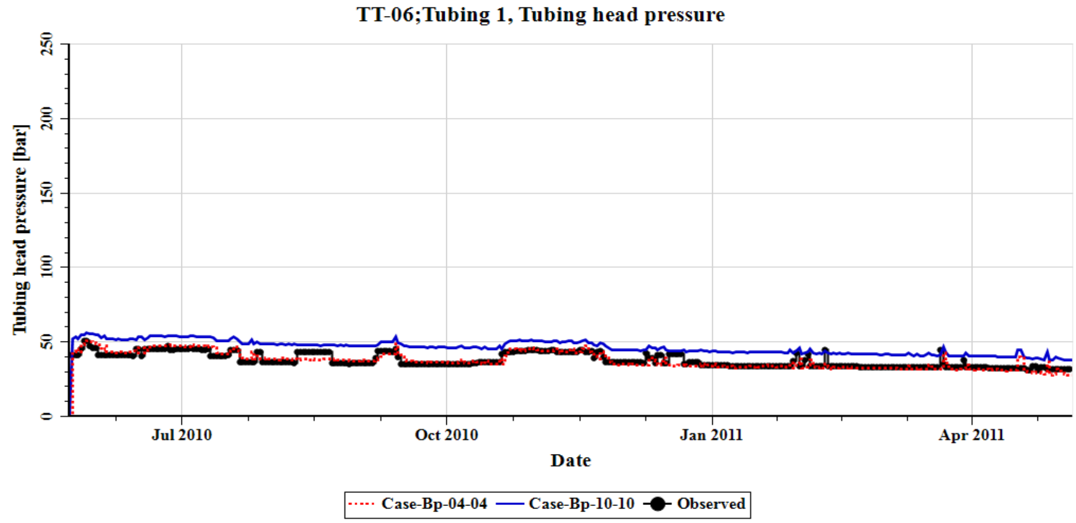


Figure 4.18 Results of the history match (WHP-TT-06)

The figure above 4.18 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-06

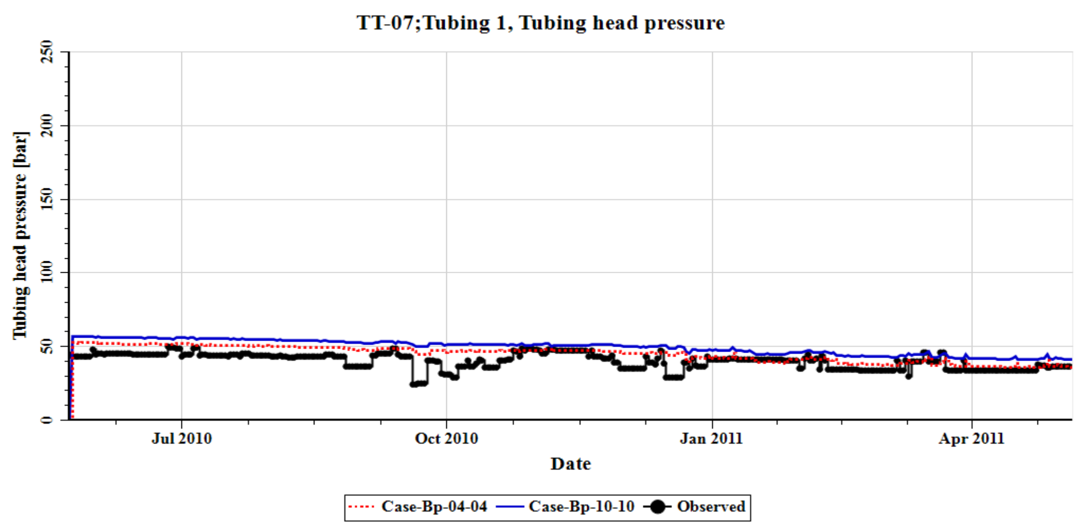


Figure 4.19 Results of the history match (WHP-TT-07)

The figure above 4.19 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-07

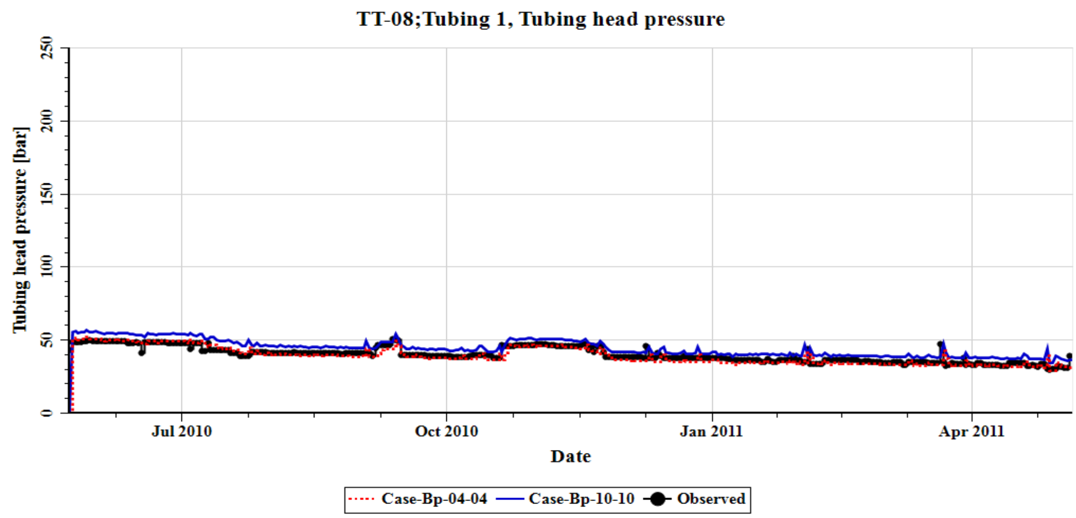


Figure 4.20 Results of the history match (WHP-TT-08)

The figure above 4.20 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-08

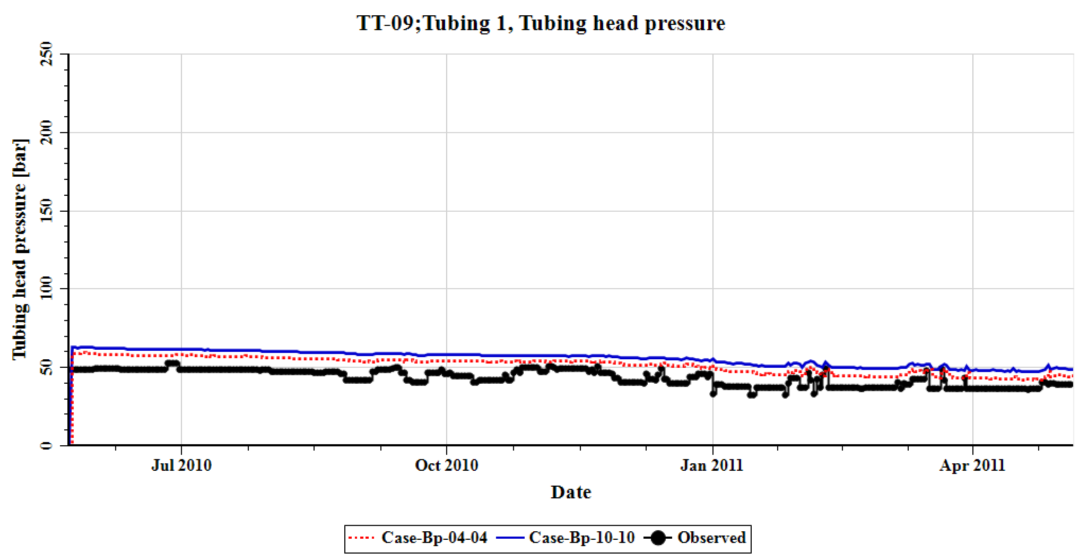


Figure 4.21 Results of the history match (WHP-TT-09)

The figure above 4.21 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the tubing well head pressure of the producer TT-09

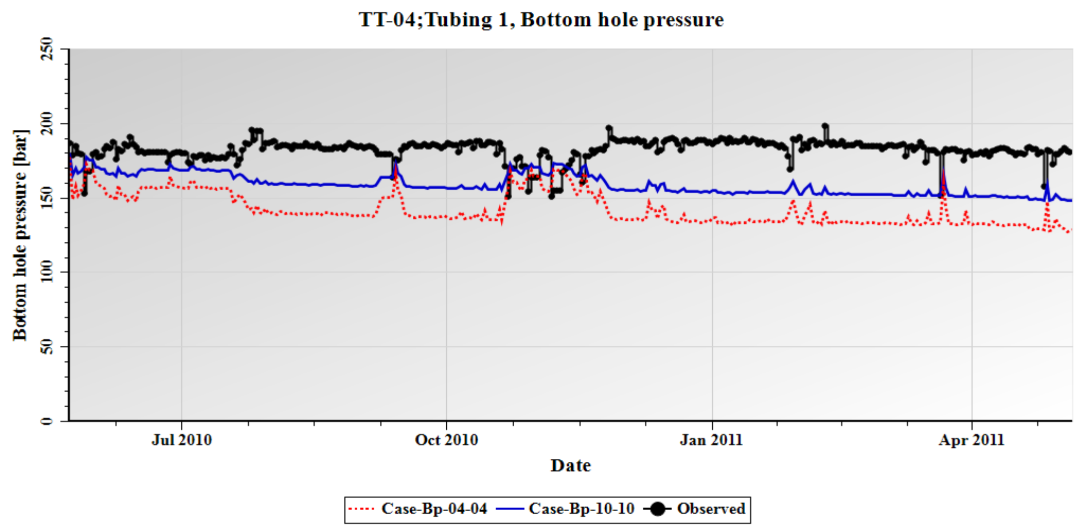


Figure 4.22 Results of the history match (BHP-TT-04)

The figure above 4.22 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-04

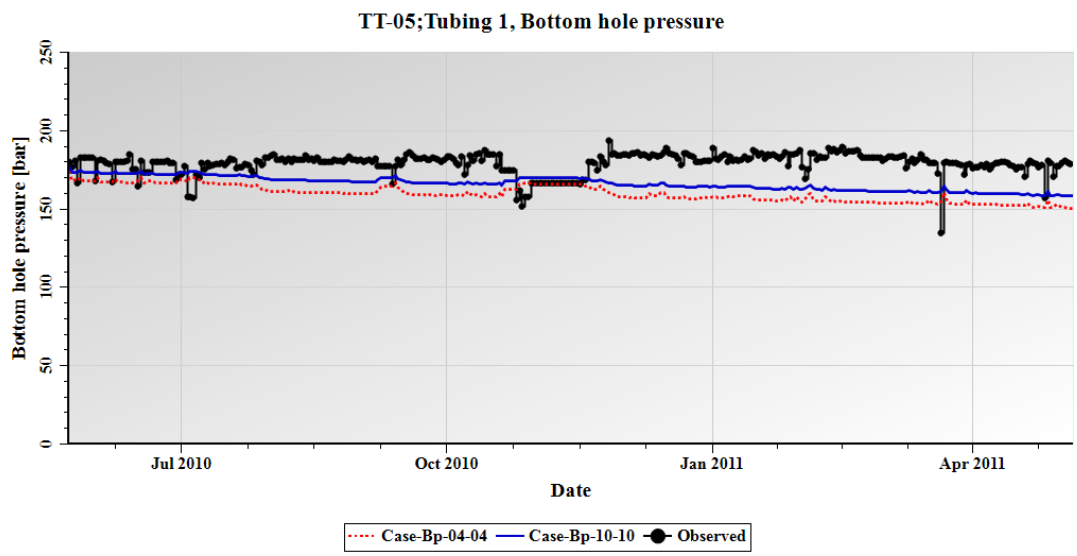


Figure 4.23 Results of the history match (BHP-TT-05)

The figure above 4.23 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-05

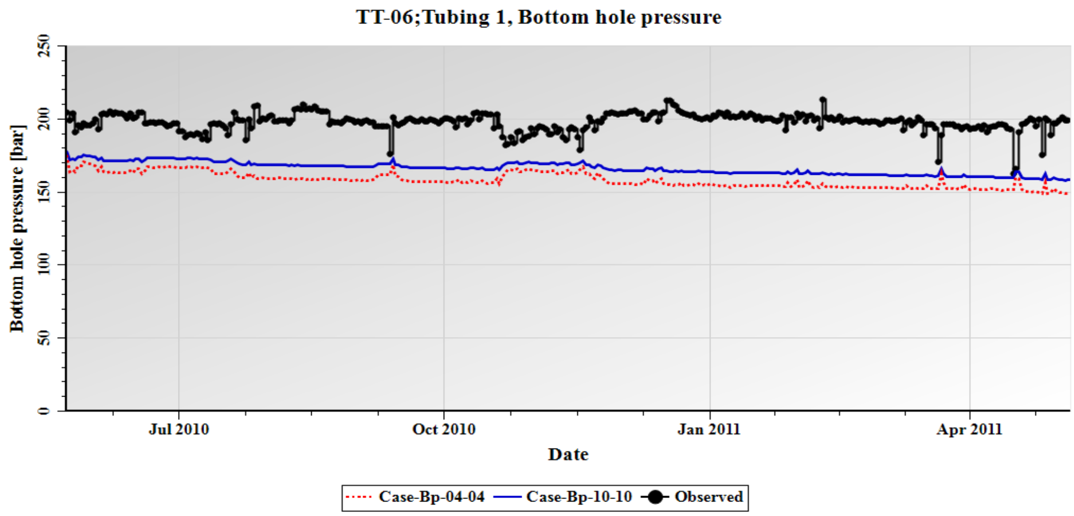


Figure 4.24 Results of the history match (BHP-TT-06)

The figure above 4.24 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-06

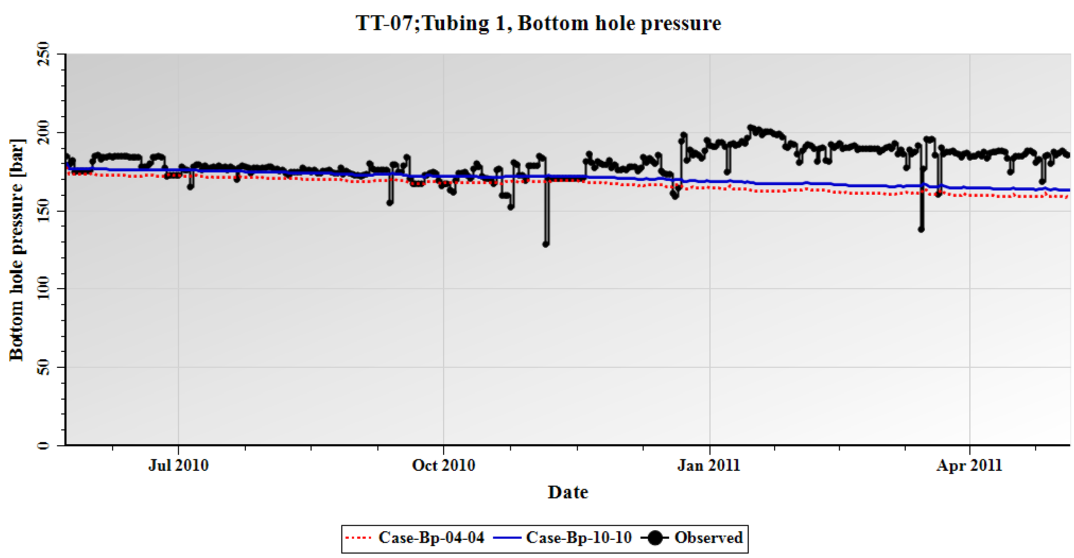


Figure 4.25 Results of the history match (BHP-TT-07)

The figure above 4.25 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-07

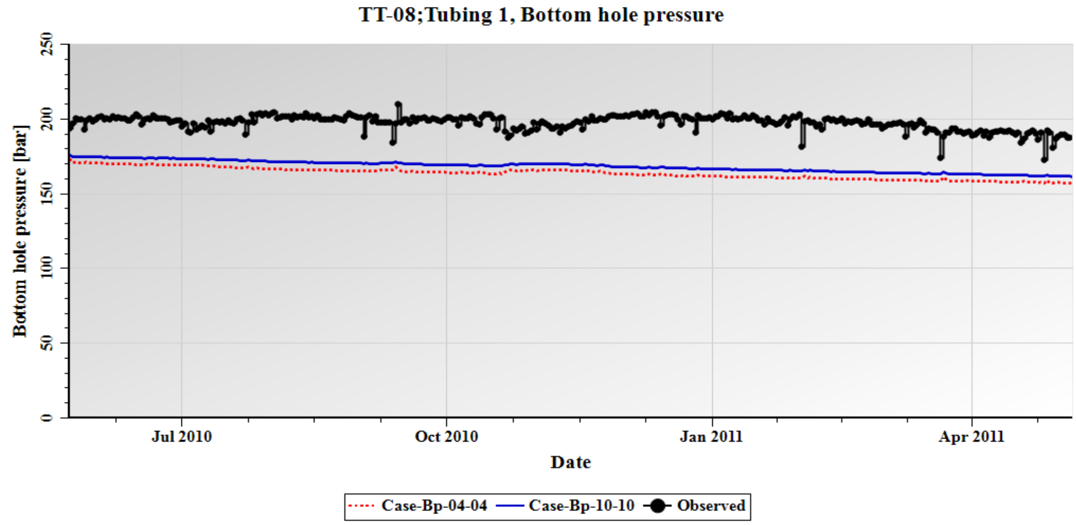


Figure 4.26 Results of the history match (BHP-TT-08)

The figure above 4.26 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-08

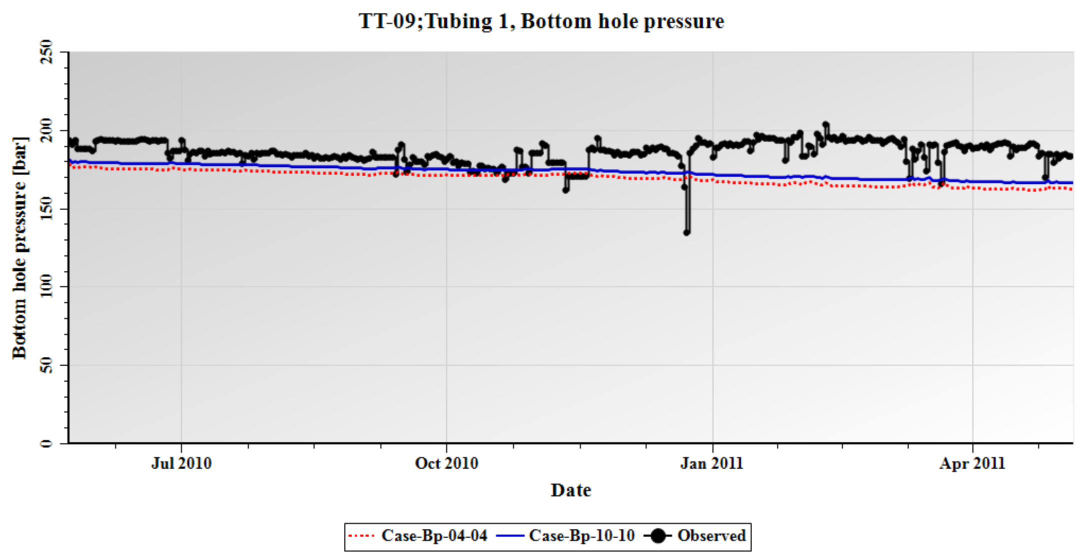


Figure 4.27 Results of the history match (BHP-TT-09)

The figure above 4.27 is presenting the comparison between the observed date (black line with filled black circle), simulation Case-Bp-04-04 (red dotted line) and simulation Case-Bp-10-10 (the blue solid line) for the bottom hole pressure of the producer TT-09

4.2 Predictions

4.2.1 Oil production rates

After obtaining the matching case, running prediction was another target of this investigation. The prediction period started from 06.05.2011 till 31.12.2019. It is important to mention that Taq Taq oil field has been developed and other wells have been drilled after the history match period (23.05.2010 to 05.05.2011) and the new wells have been included in the prediction. The figure 4.28 below shows the location of the wells which have been included in the history match (green wells), location of the wells which have been drilled after the history match period (black wells) and three new suggested well location which have been included in the prediction too (red wells).

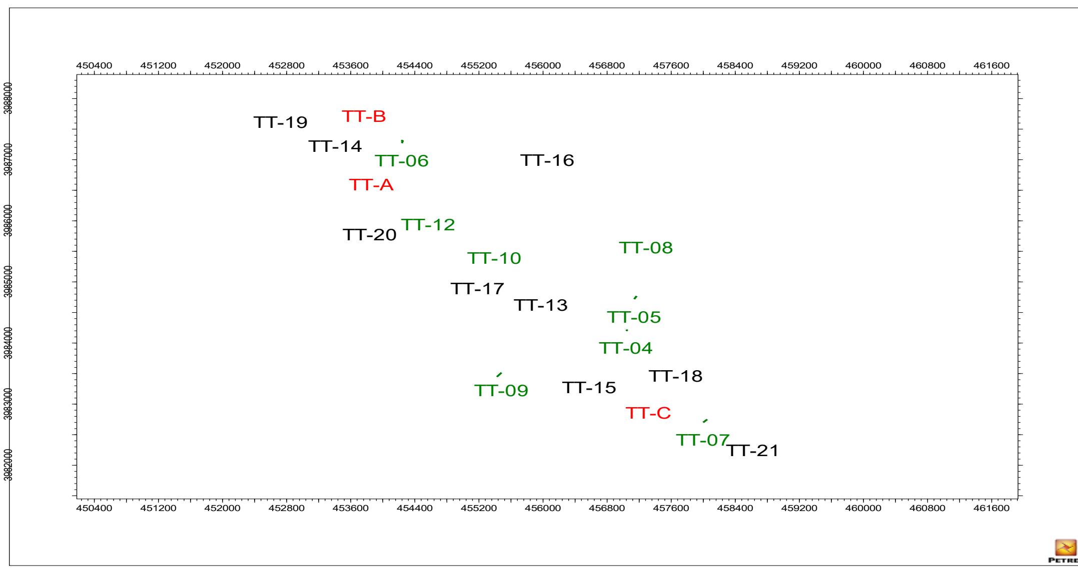


Figure 4.28 Location of the wells in Taq Taq oil field

It is obvious that there are a lot of prediction scenarios which can be apply to a certain oil field. After calibrating the three dimensional geological model via the history match process, four prediction cases have been carried out. The main condition for the prediction scenarios is producing oil for longer period without artificial lift or water injection. The table below presents the date of launching the prediction for each well, required oil rate and the pressure limit for the four scenarios.

Table 4.1 the table shows the starting and ending prediction date of each well with its oil rate target and wellhead pressure limit for four prediction cases

Wells	Group	Starting of prediction period	Ending of prediction period	Case 300 oil rate target (m^3/d)	Case 300 without 3 wells oil rate target (m^3/d)	Case 500 oil rate target (m^3/d)	Case 500 without 3 wells oil rate target (m^3/d)	All Cases WHP limit (bar)
TT-04	Group 4-12	06/05/2011	31/12/2019	2400	2400	4000	4000	10
TT-05	Group 4-12	06/05/2011	31/12/2019					
TT-06	Group 4-12	06/05/2011	31/12/2019					
TT-07	Group 4-12	06/05/2011	31/12/2019					
TT-08	Group 4-12	06/05/2011	31/12/2019					
TT-09	Group 4-12	06/05/2011	31/12/2019					
TT-10	Group 4-12	06/05/2011	31/12/2019					
TT-12	Group 4-12	06/05/2011	31/12/2019					
TT-13	Group 13	01/08/2011	31/12/2019	300	300	500	500	
TT-14	Group 14	01/09/2011	31/12/2019	300	300	500	500	
TT-15	Group 15	01/11/2011	31/12/2019	300	300	500	500	
TT-16	Group 16	01/02/2012	31/12/2019	300	300	500	500	
TT-17	Group 17	01/04/2012	31/12/2019	300	300	500	500	
TT-18	Group 18	01/02/2013	31/12/2019	300	300	500	500	
TT-19	Group 19	01/07/2012	31/12/2019	300	300	500	500	
TT-20	Group 20	01/09/2013	31/12/2019	300	300	500	500	
TT-21	Group 21	01/06/2013	31/12/2019	300	300	500	500	
TT-A	Group A-C	01/01/2014	31/12/2019	900	0	1500	0	
TT-B	Group A-C	01/01/2014	31/12/2019					
TT-C	Group A-C	01/01/2014	31/12/2019					

The following figures are showing the results of the four prediction scenarios in which the performance for each well and the field will appear clearly in terms of oil production rate, bottom hole pressure and well head pressure. It is important to mention that the flow rate is natural and it is without any artificial lift.

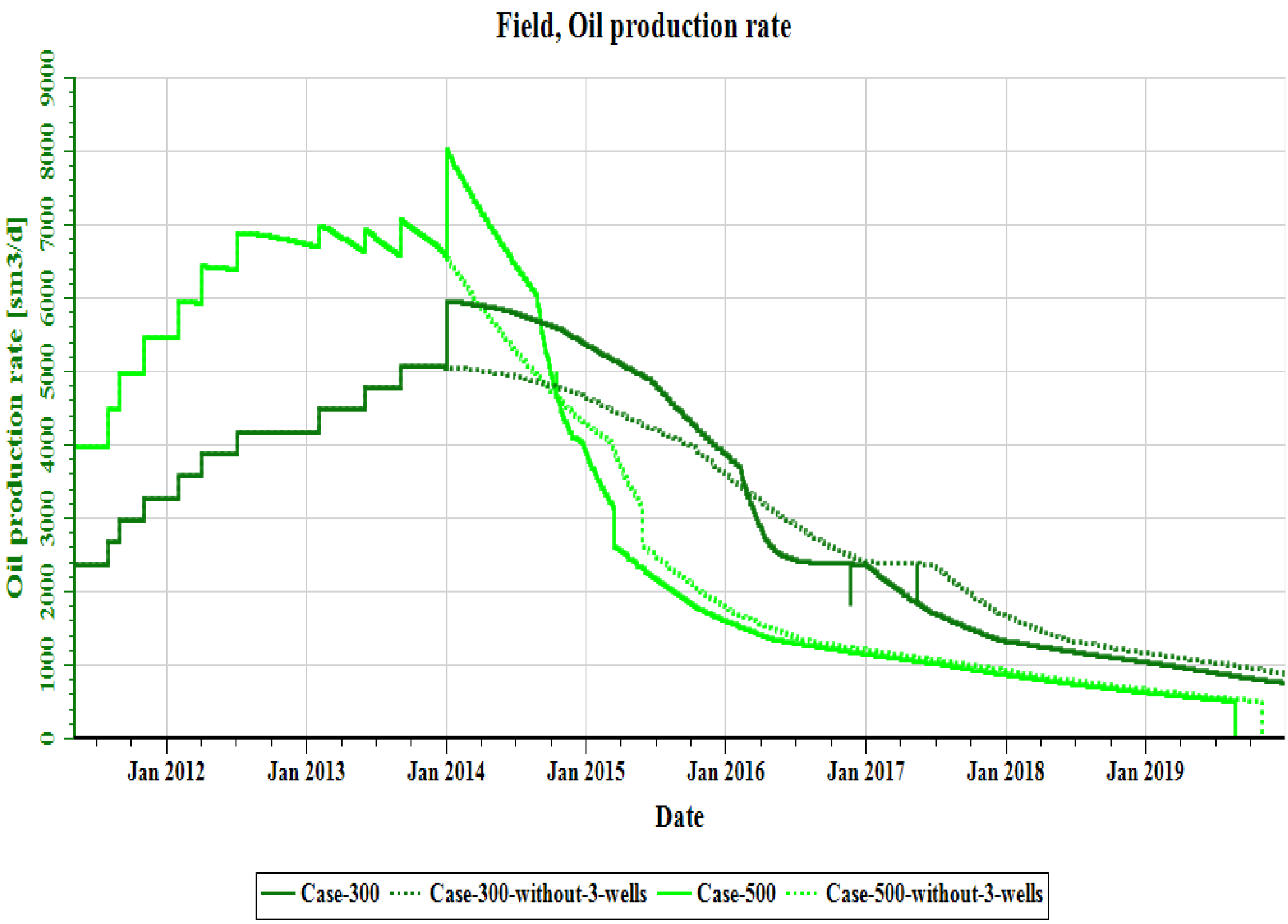


Figure 4.29 Results of prediction cases (Oil - Field)

The plot above 4.29 is showing the oil forecasting for four different cases for the field. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

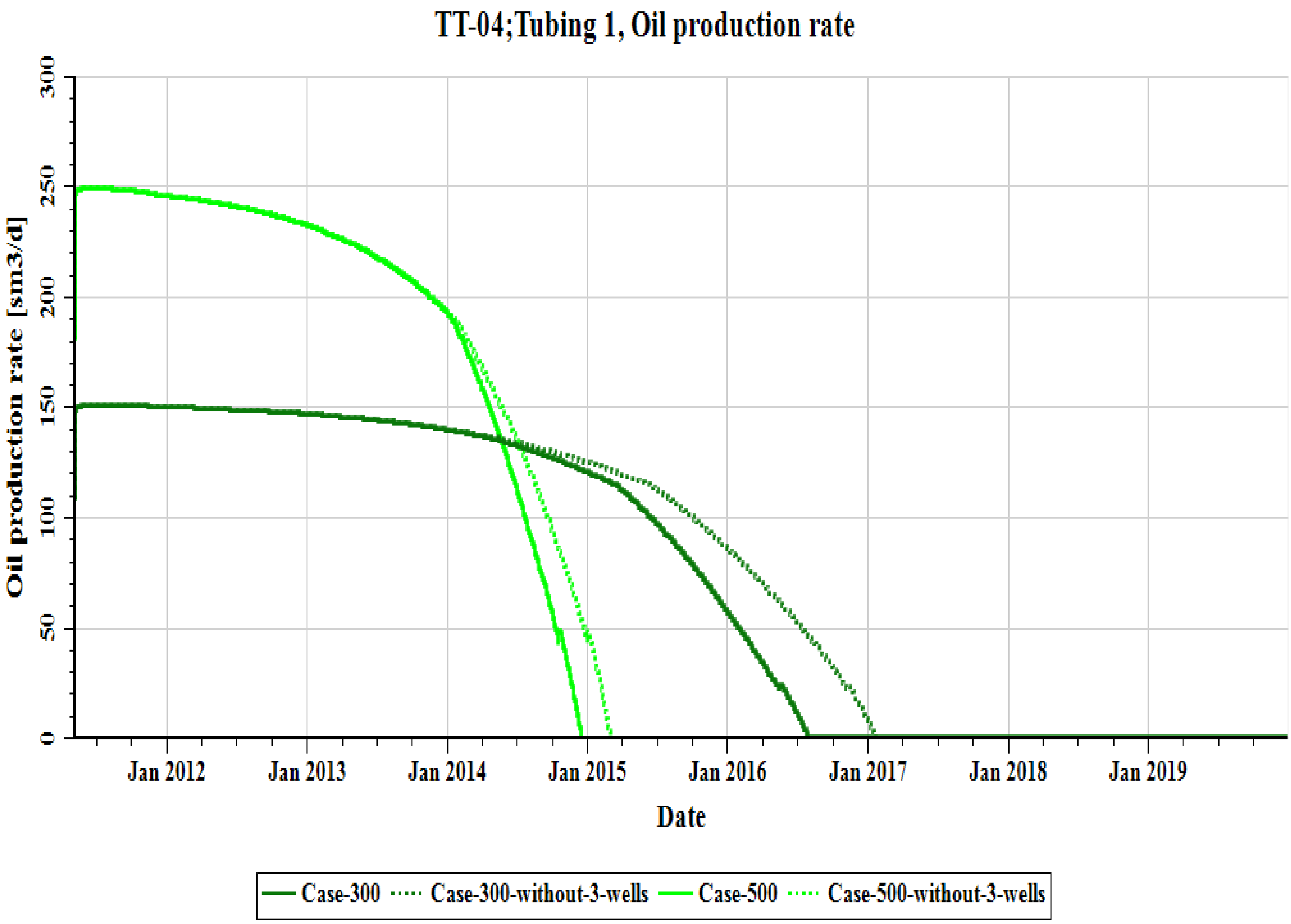


Figure 4.30 Results of prediction cases (Oil -TT-04)

The plot above 4.30 is showing the oil forecasting for four different cases for the TT-04. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

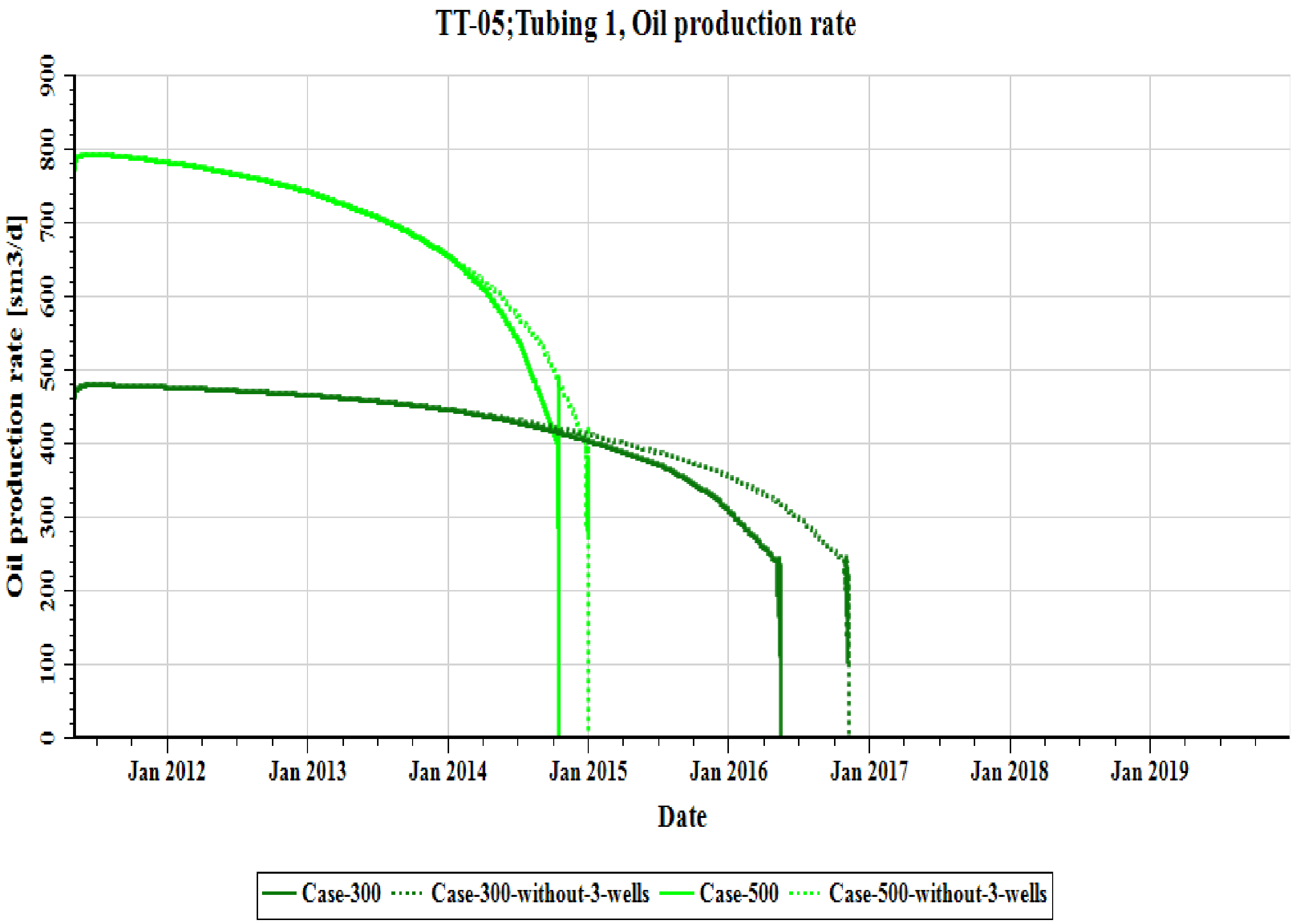


Figure 4.31 Results of prediction cases (Oil -TT-05)

The plot above 4.31 is showing the oil forecasting for four different cases for the TT-05. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

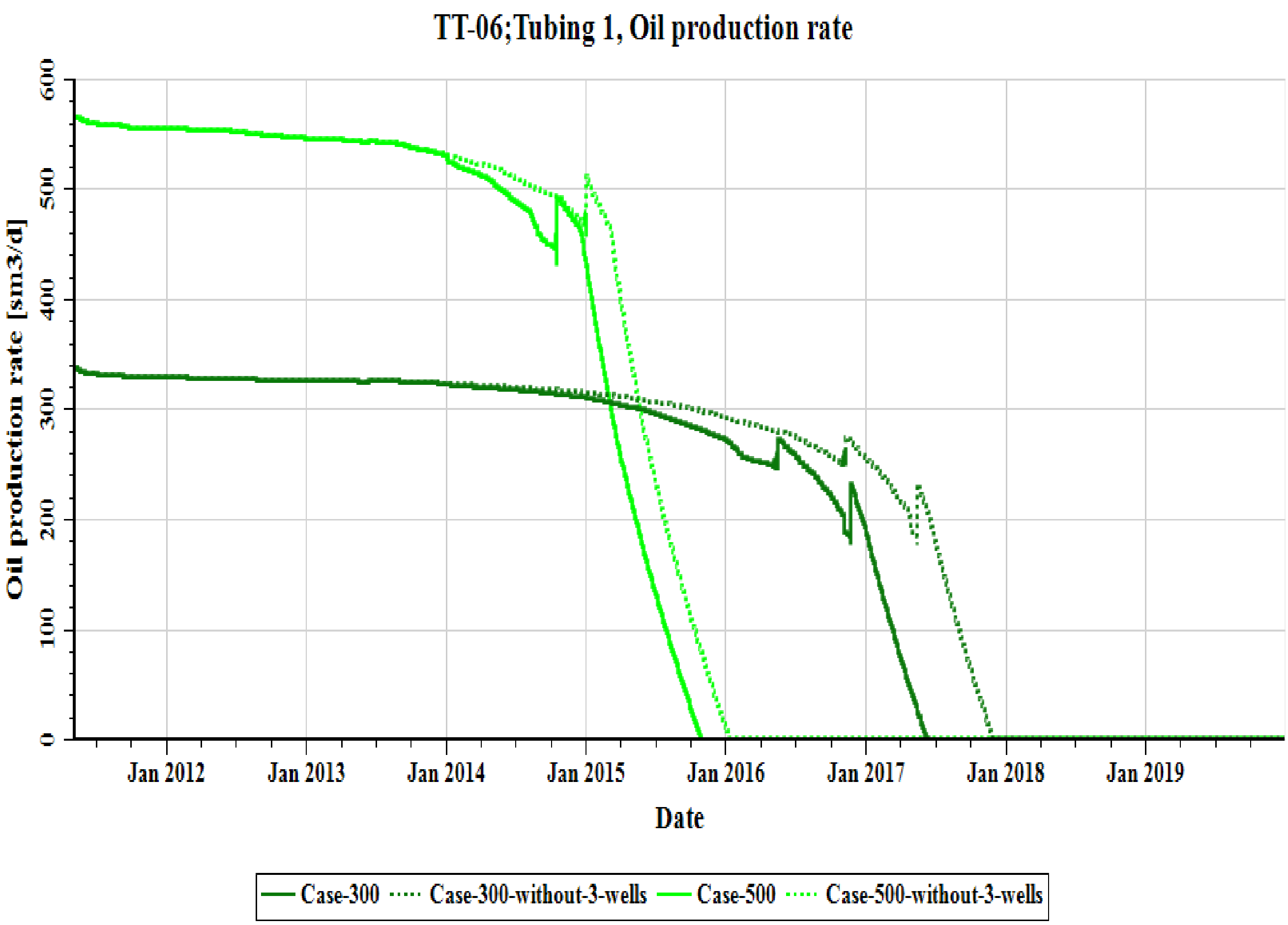


Figure 4.32 Results of prediction cases (Oil -TT-06)

The plot above 4.32 is showing the oil forecasting for four different cases for the TT-06. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

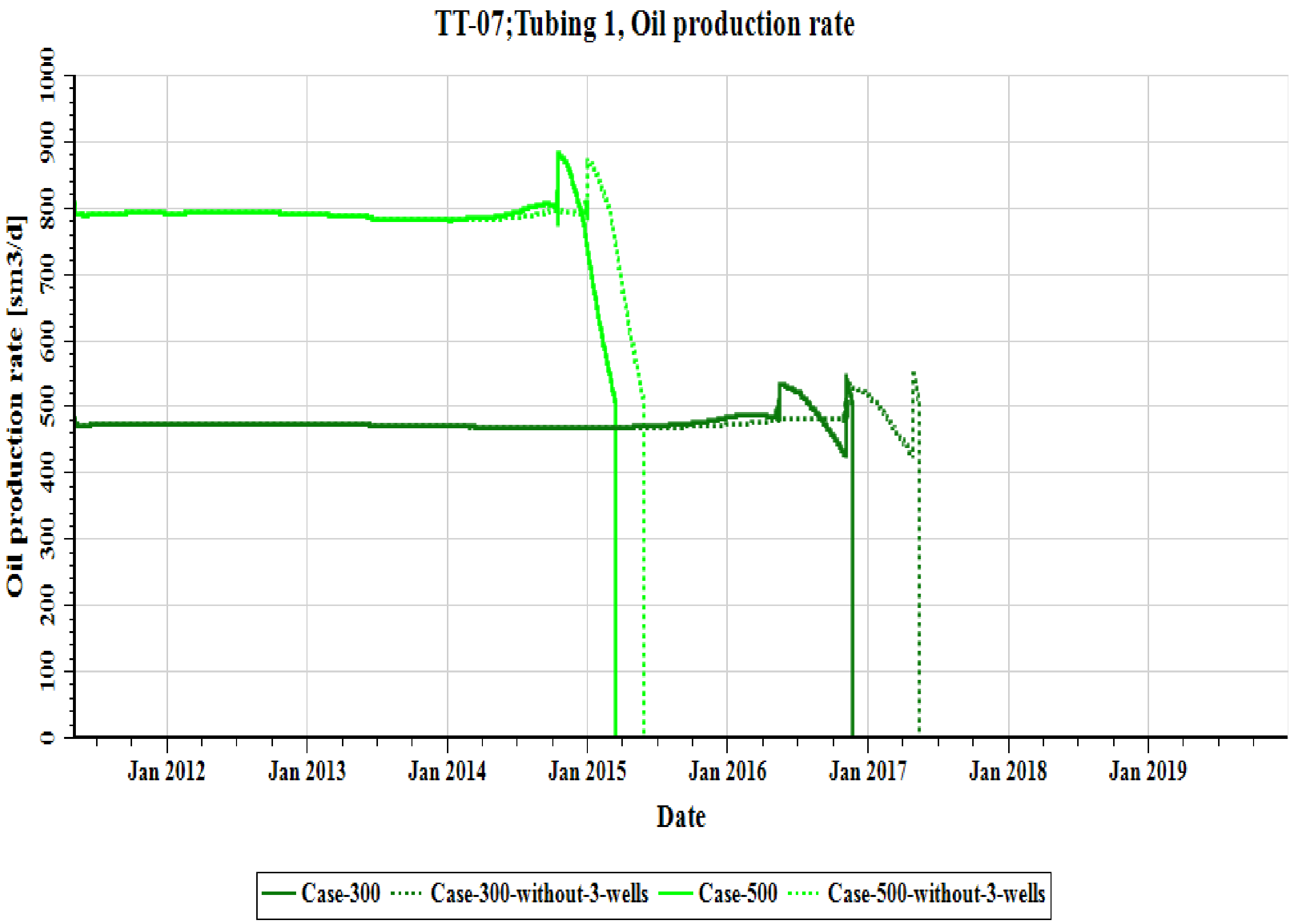


Figure 4.33 Results of prediction cases (Oil -TT-07)

The plot above 4.33 is showing the oil forecasting for four different cases for the TT-07. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

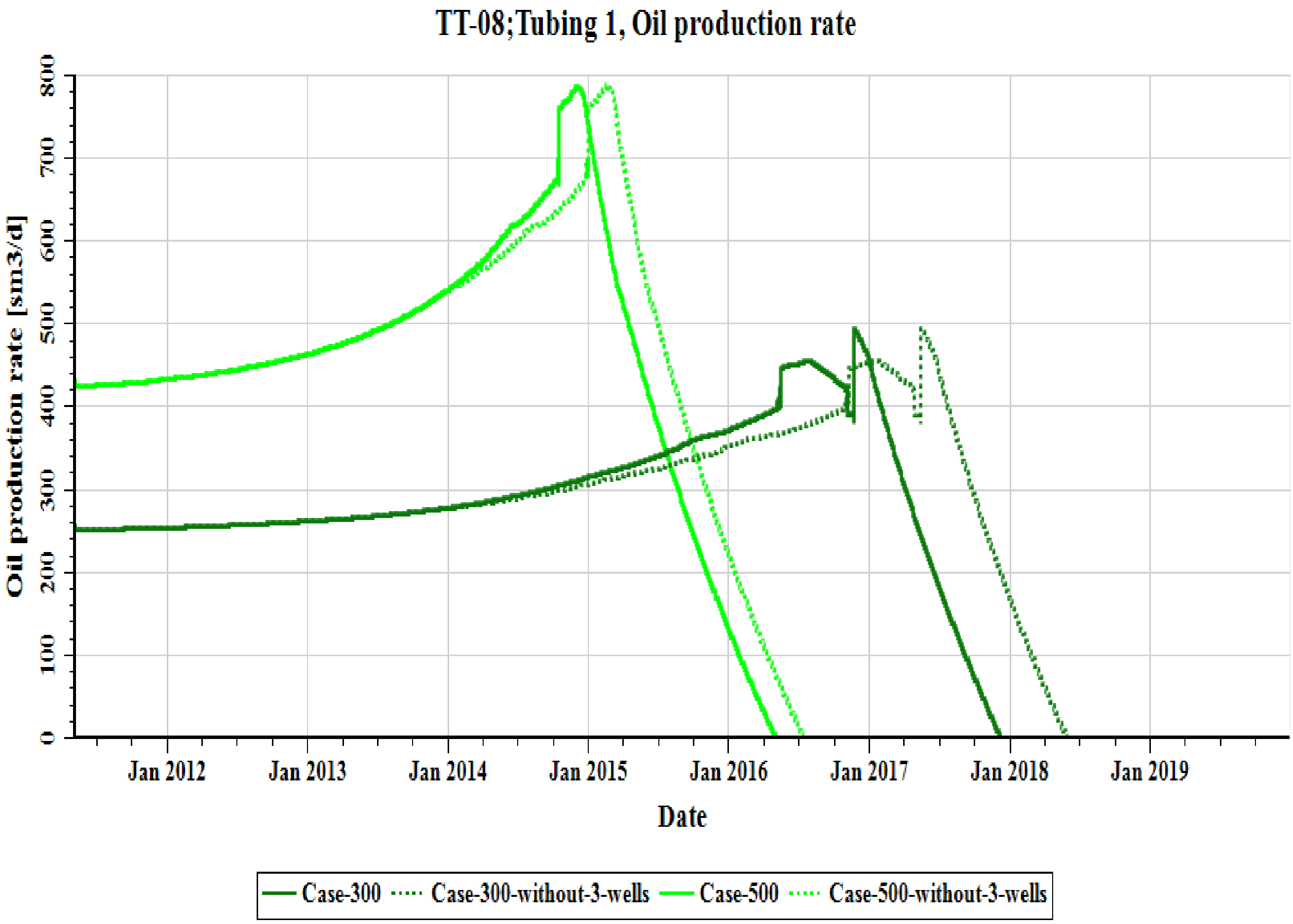


Figure 4.34 Results of prediction cases (Oil -TT-08)

The plot above 4.34 is showing the oil forecasting for four different cases for the TT-08. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

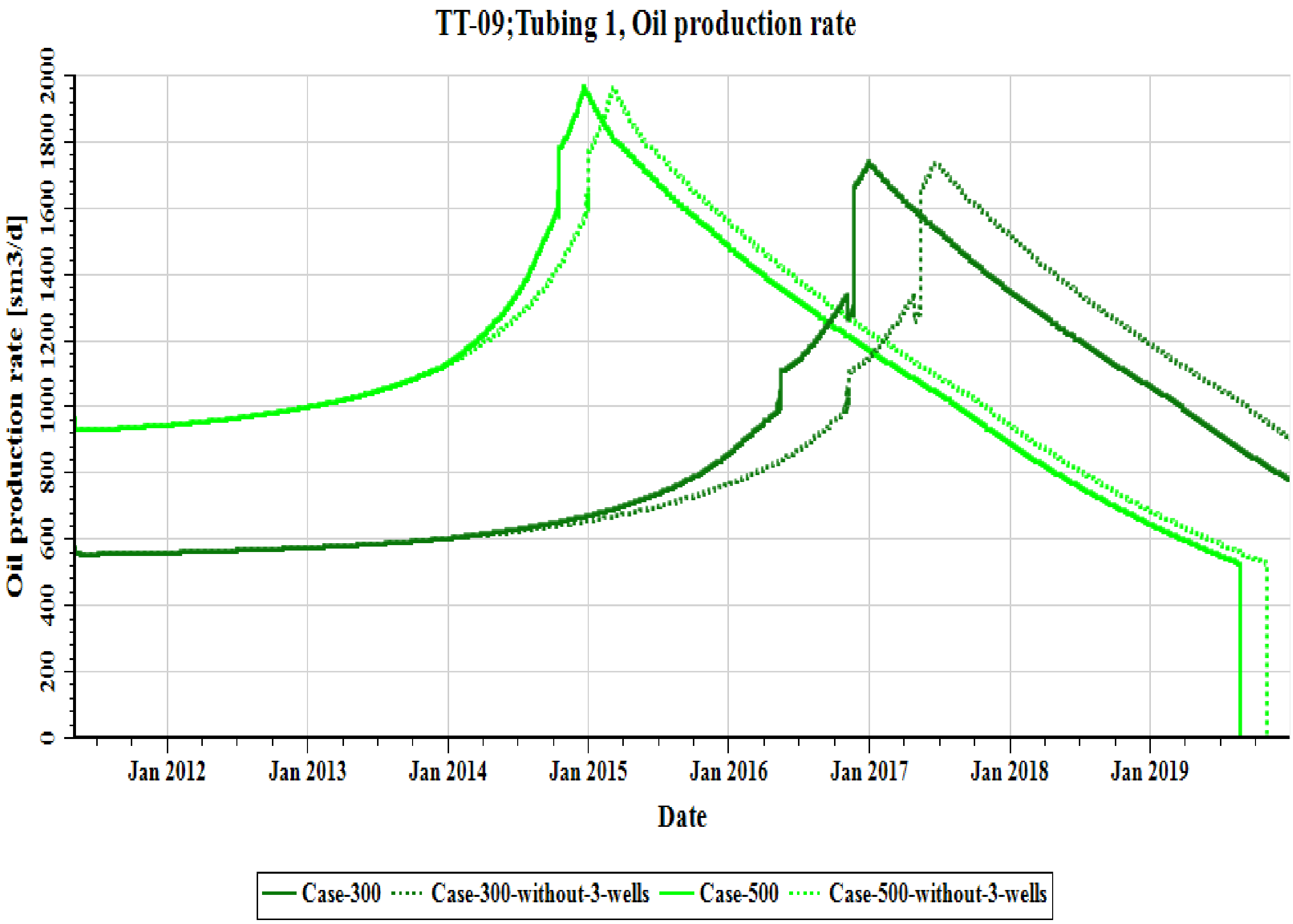


Figure 4.35 Results of prediction cases (Oil TT-09)

The plot above 4.35 is showing the oil forecasting for four different cases for the TT-09. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

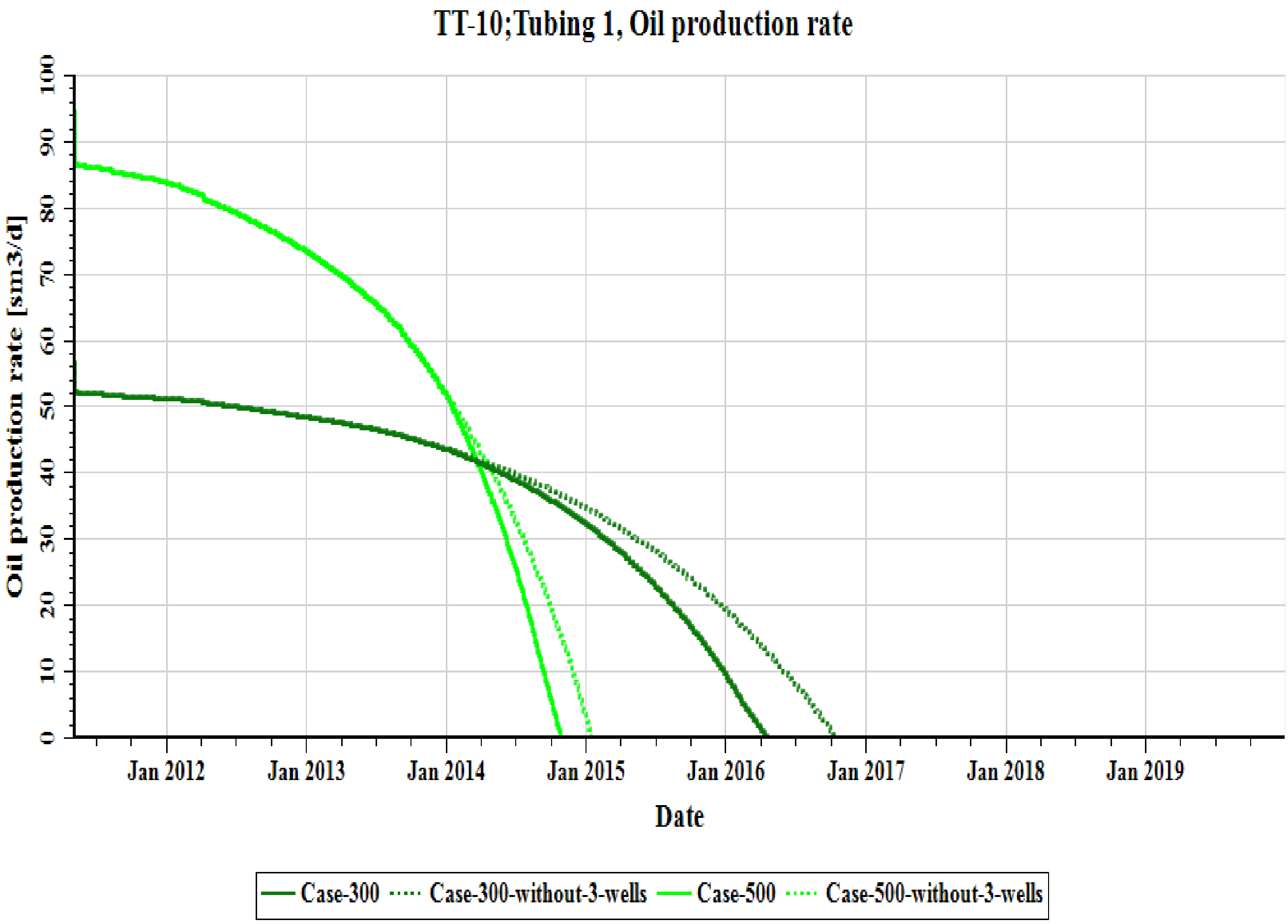


Figure 4.36 Results of prediction cases (Oil -TT-10)

The plot above 4.36 is showing the oil forecasting for four different cases for the TT-10. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

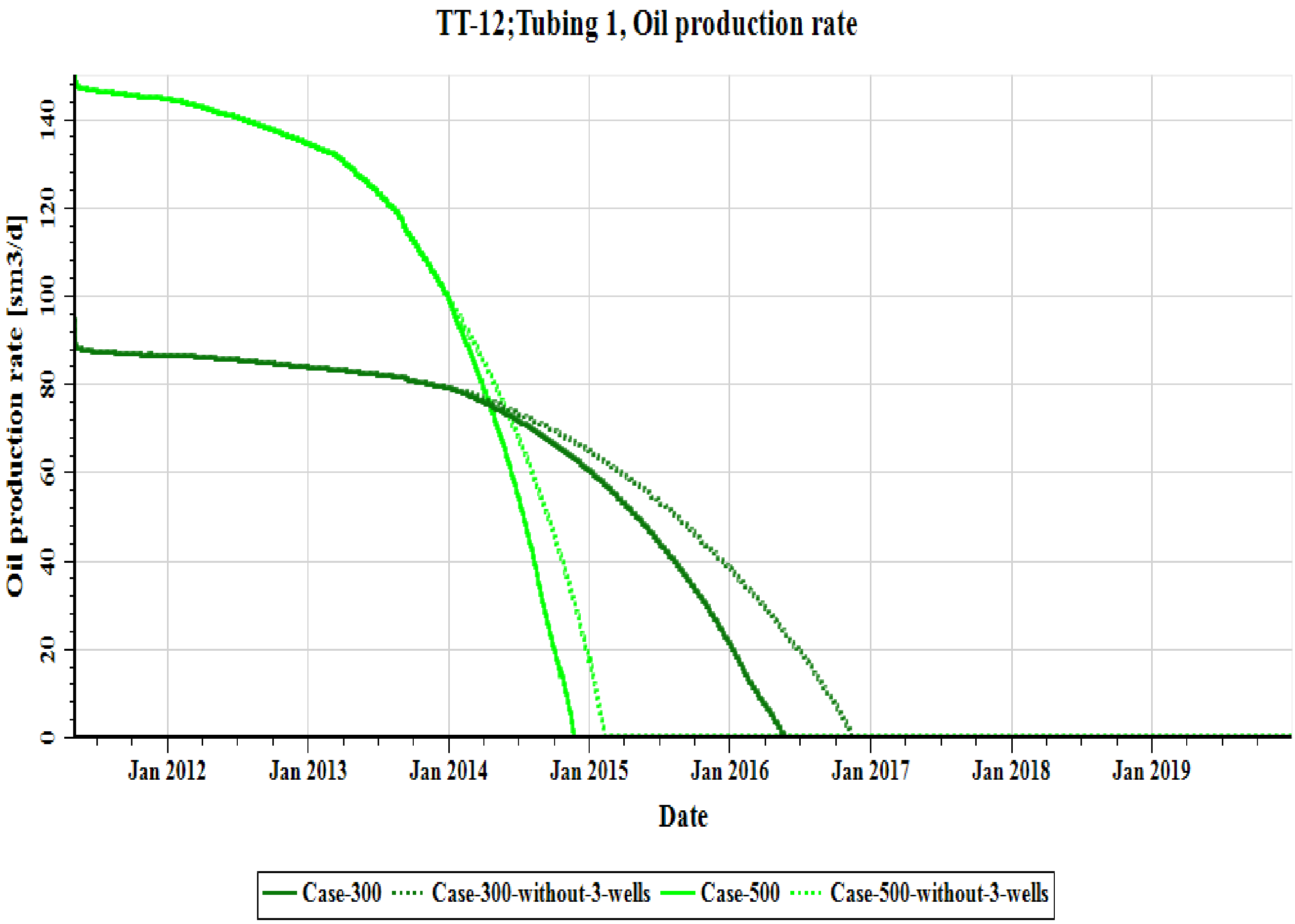


Figure 4.37 Results of prediction cases (Oil -TT-12)

The plot above 4.37 is showing the oil forecasting for four different cases for the TT-12. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

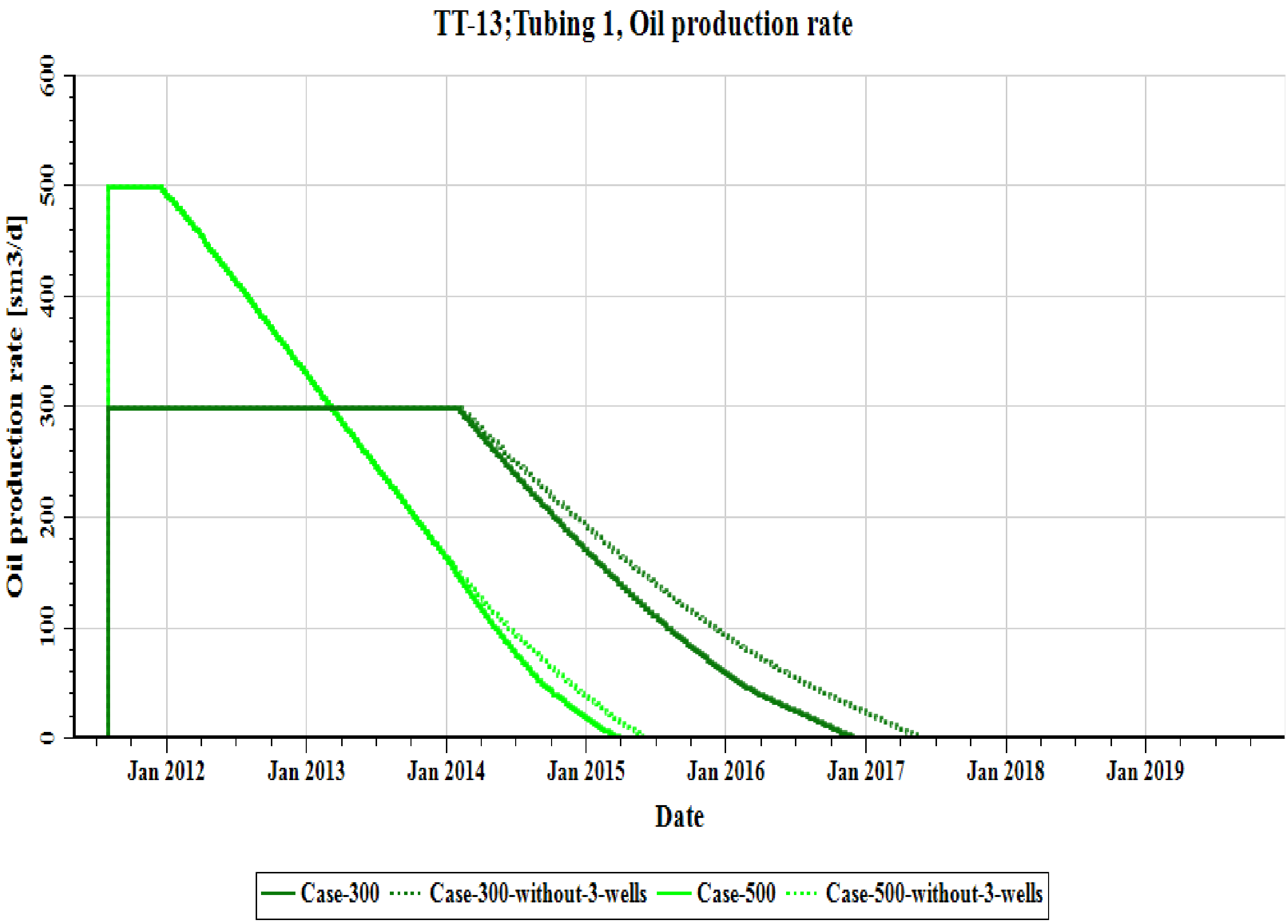


Figure 4.38 Results of prediction cases (Oil -TT-13)

The plot above 4.38 is showing the oil forecasting for four different cases for the TT-13. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

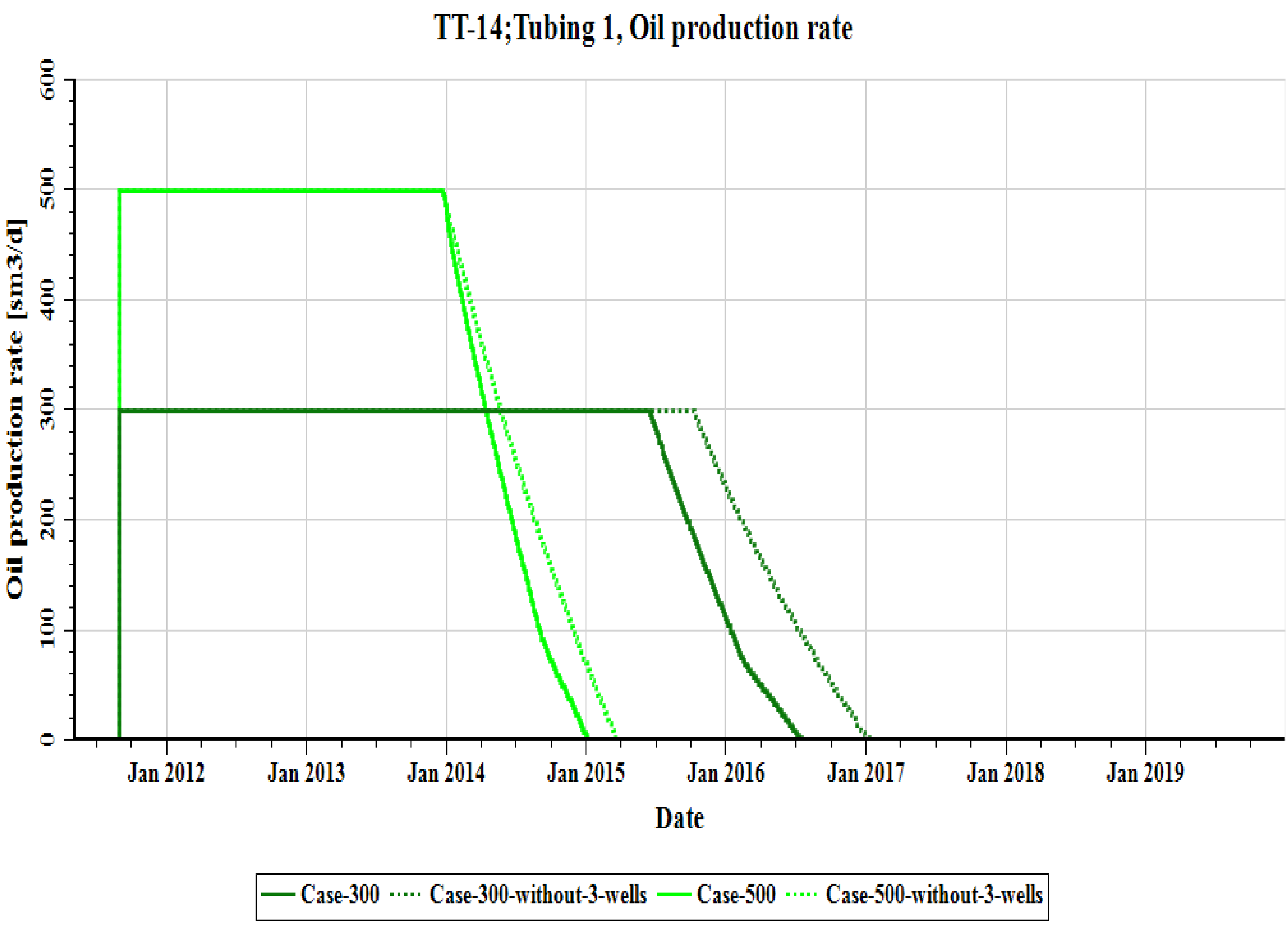


Figure 4.39 Results of prediction cases (Oil -TT-14)

The plot above 4.39 is showing the oil forecasting for four different cases for the TT-14. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

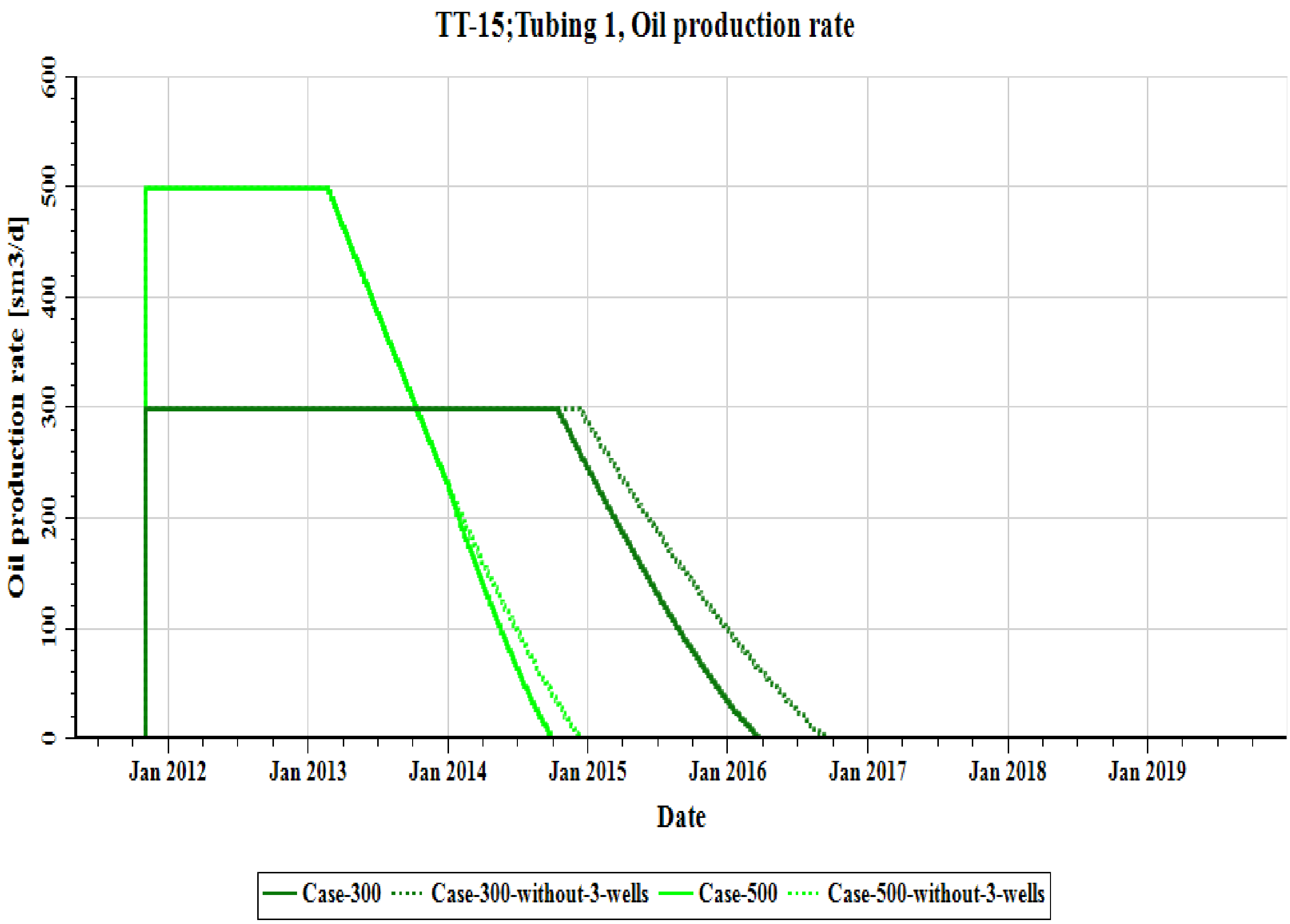


Figure 4.40 Results of prediction cases (Oil -TT-15)

The plot above 4.40 is showing the oil forecasting for four different cases for the TT-15. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

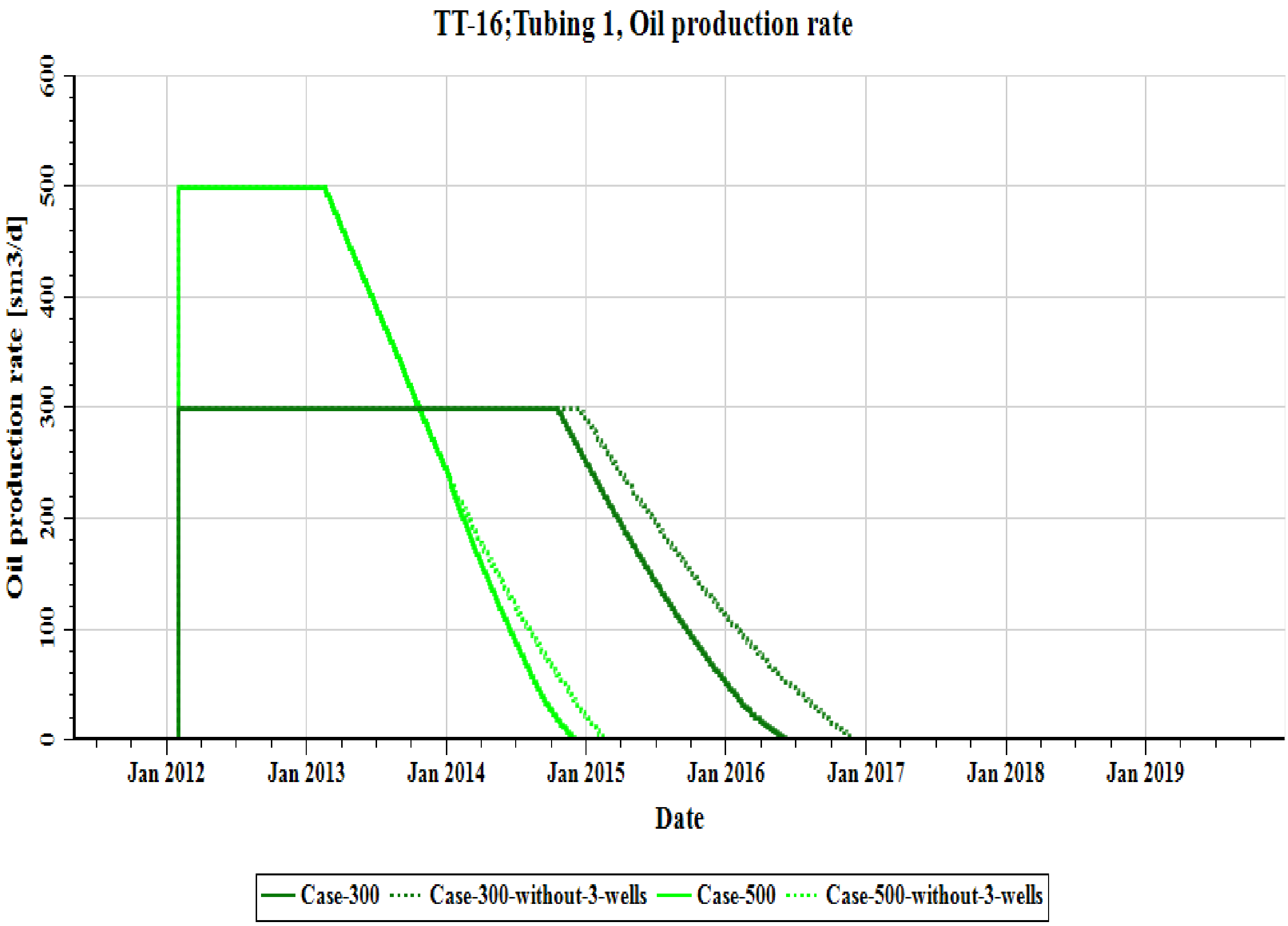


Figure 4.41 Results of prediction cases (Oil -TT-16)

The plot above 4.41 is showing the oil forecasting for four different cases for the TT-16. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

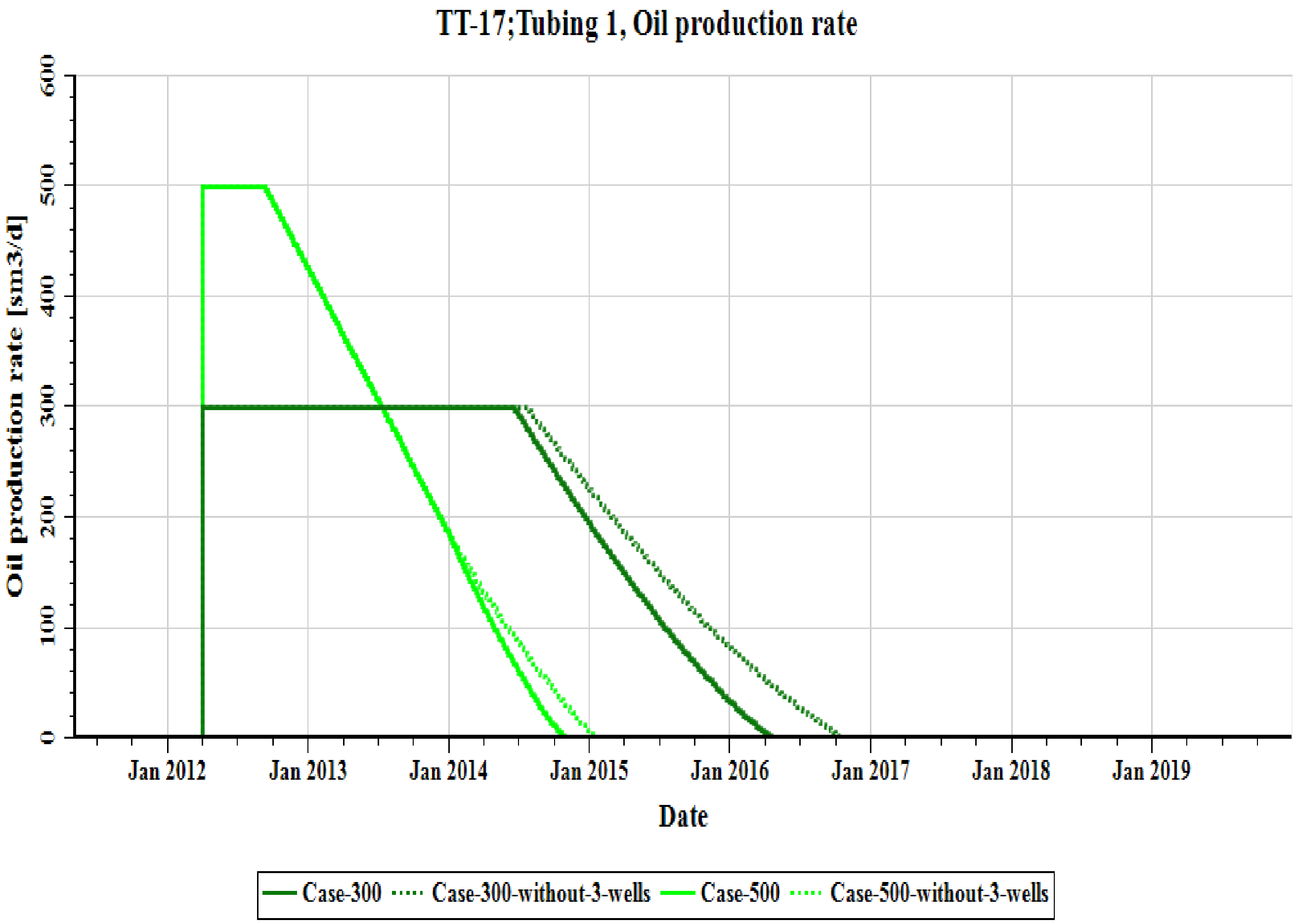


Figure 4.42 Results of prediction cases (Oil -TT-17)

The plot above 4.42 is showing the oil forecasting for four different cases for the TT-17. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

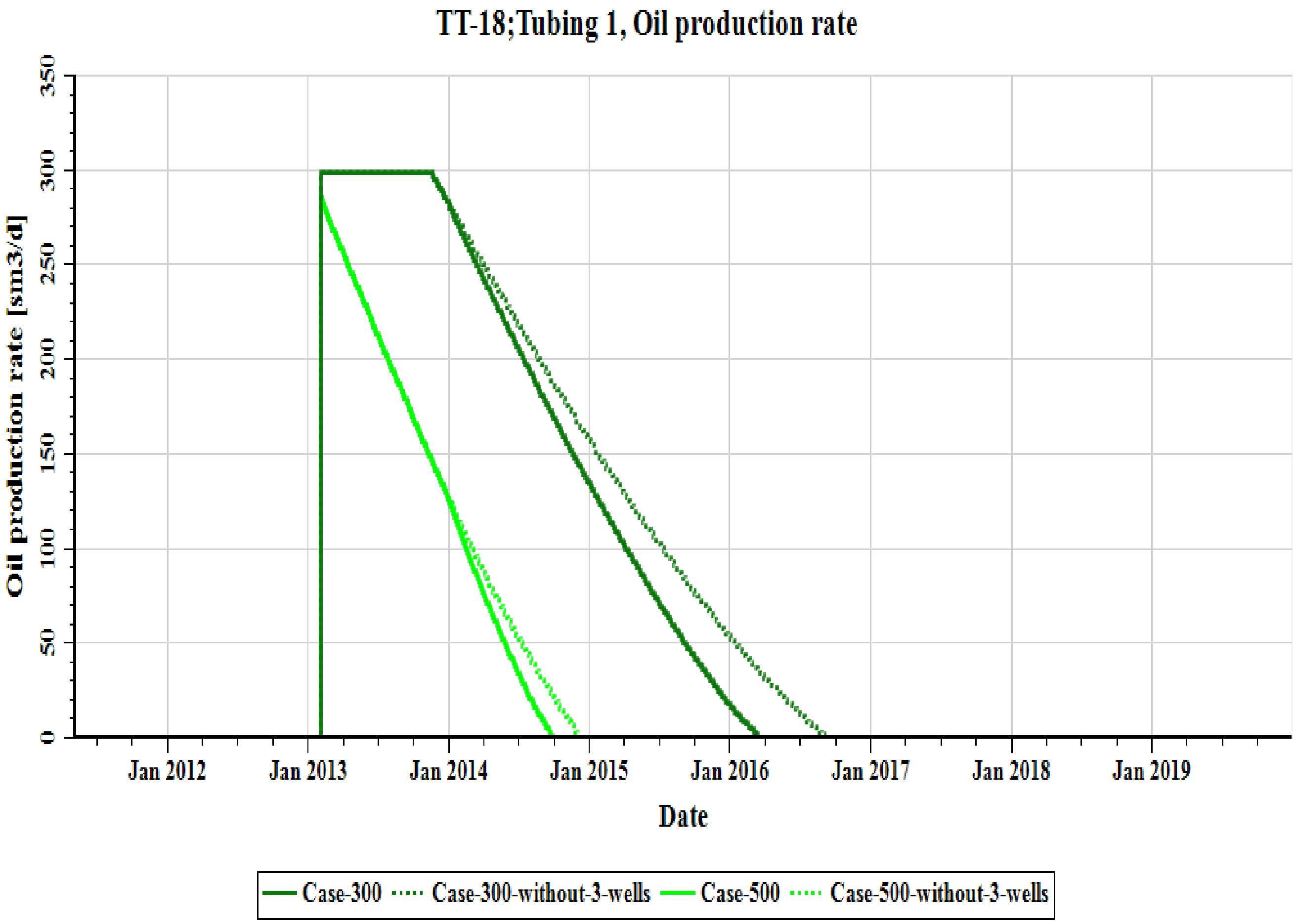


Figure 4.43 Results of prediction cases (Oil -TT-18)

The plot above 4.43 is showing the oil forecasting for four different cases for the TT-18. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

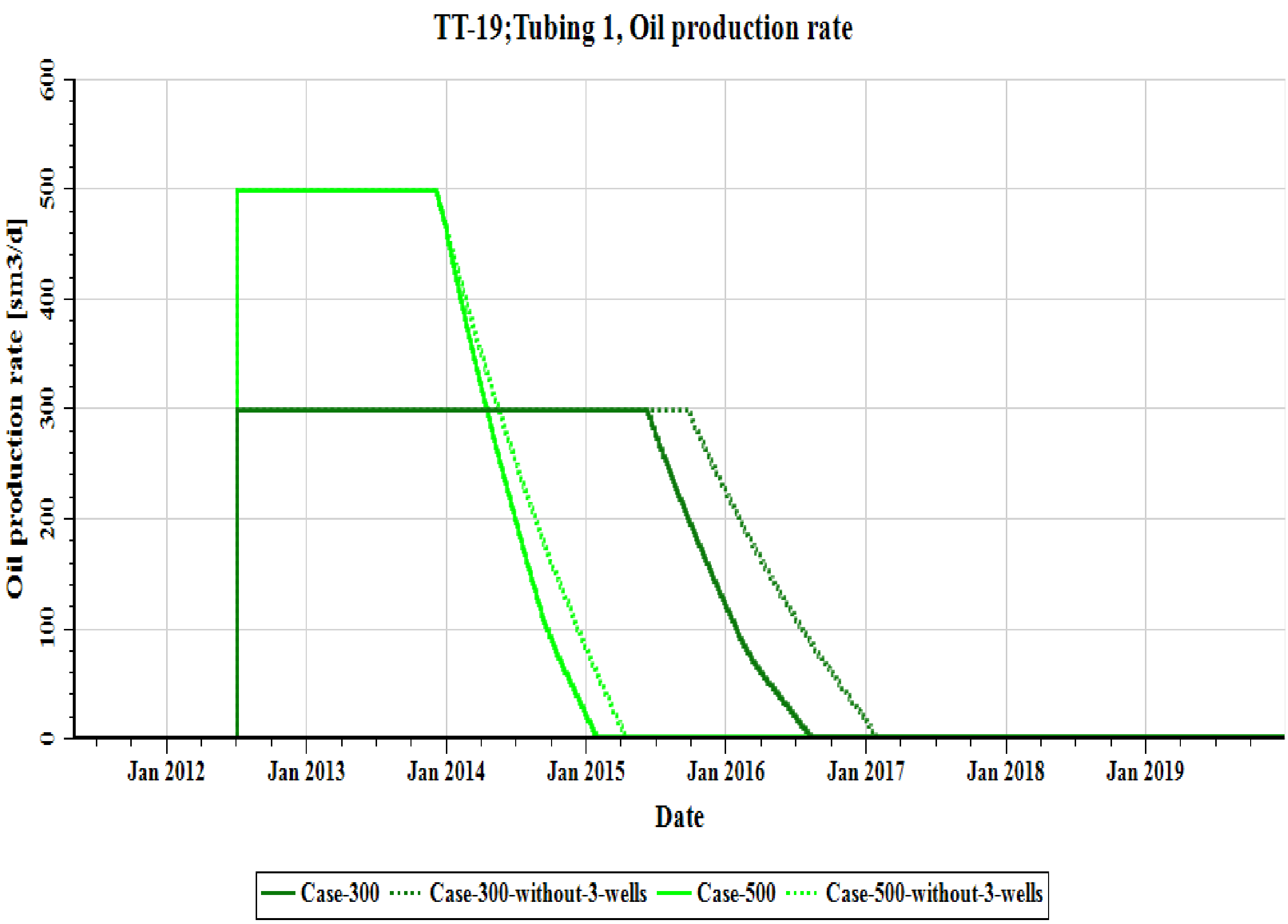


Figure 4.44 Results of prediction cases (Oil -TT-19)

The plot above 4.44 is showing the oil forecasting for four different cases for the TT-19. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

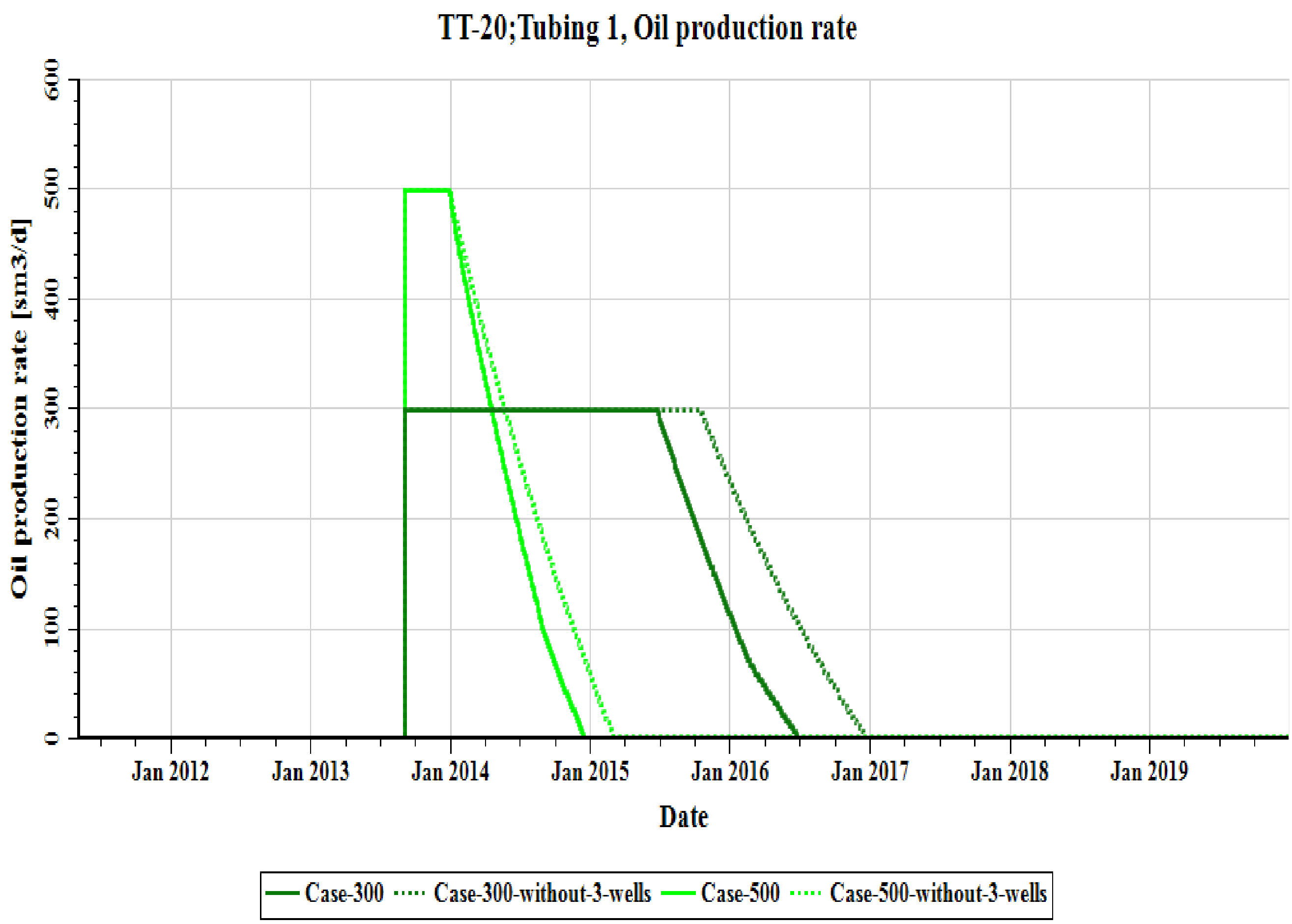


Figure 4.45 Results of prediction cases (Oil -TT-20)

The plot above 4.45 is showing the oil forecasting for four different cases for the TT-20. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

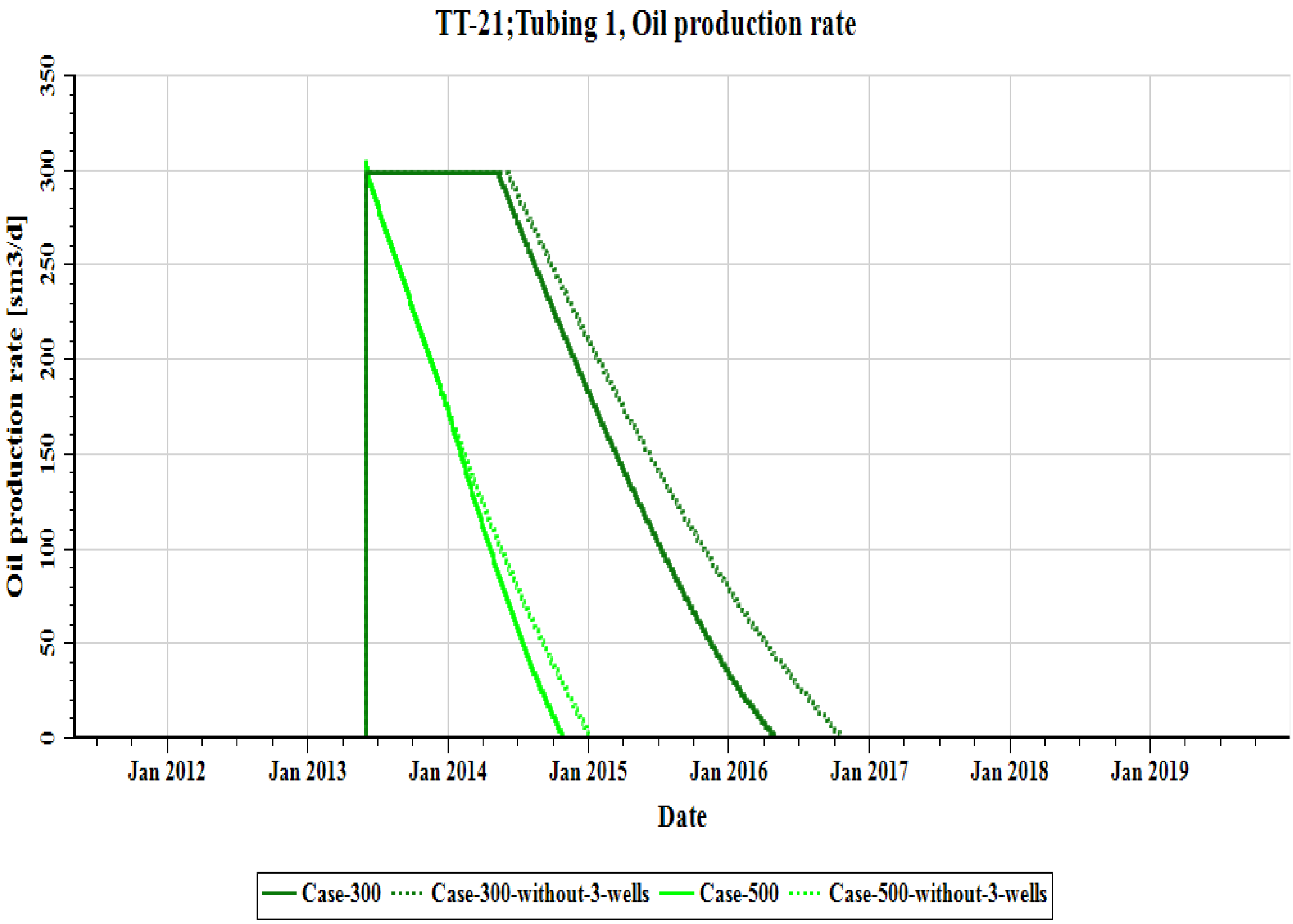


Figure 4.46 Results of prediction cases (Oil -TT-21)

The plot above 4.46 is showing the oil forecasting for four different cases for the TT-21. The solid dark green line and the dotted dark green line are representing case-300 and case-300 without 3 suggested wells respectively (less excessive production rate) whereas the solid light green line and dotted light green line are representing the case-500 and case-500 without the 3 suggested wells respectively (more excessive production rate).

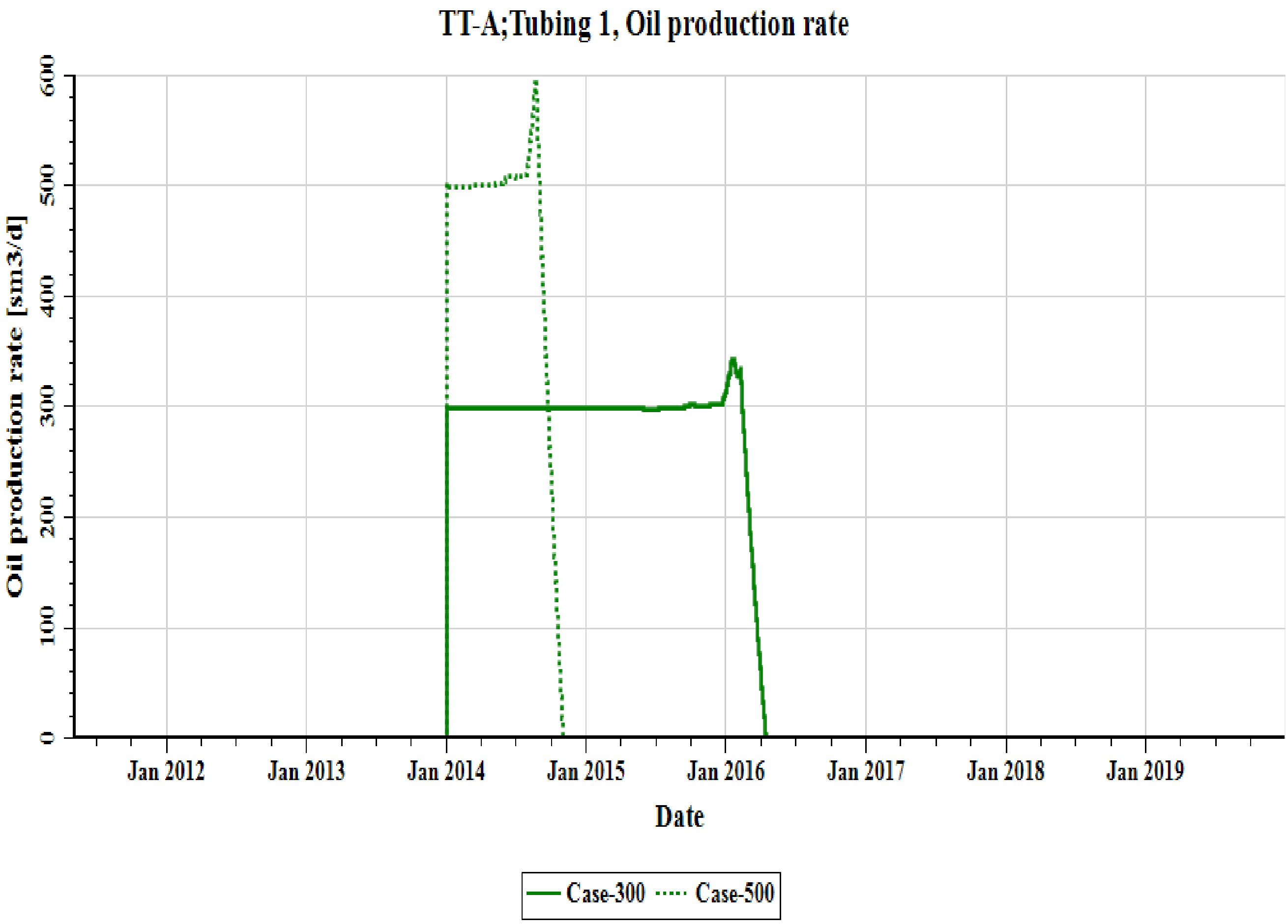


Figure 4.47 Results of prediction cases (Oil -TT-A)

The plot above 4.47 is showing the oil forecasting for two different cases for the TT-A (one of three suggested wells). The solid dark green line and the dotted dark green line are representing case-300 (less excessive production rate) and case-500 (more excessive production rate) respectively.

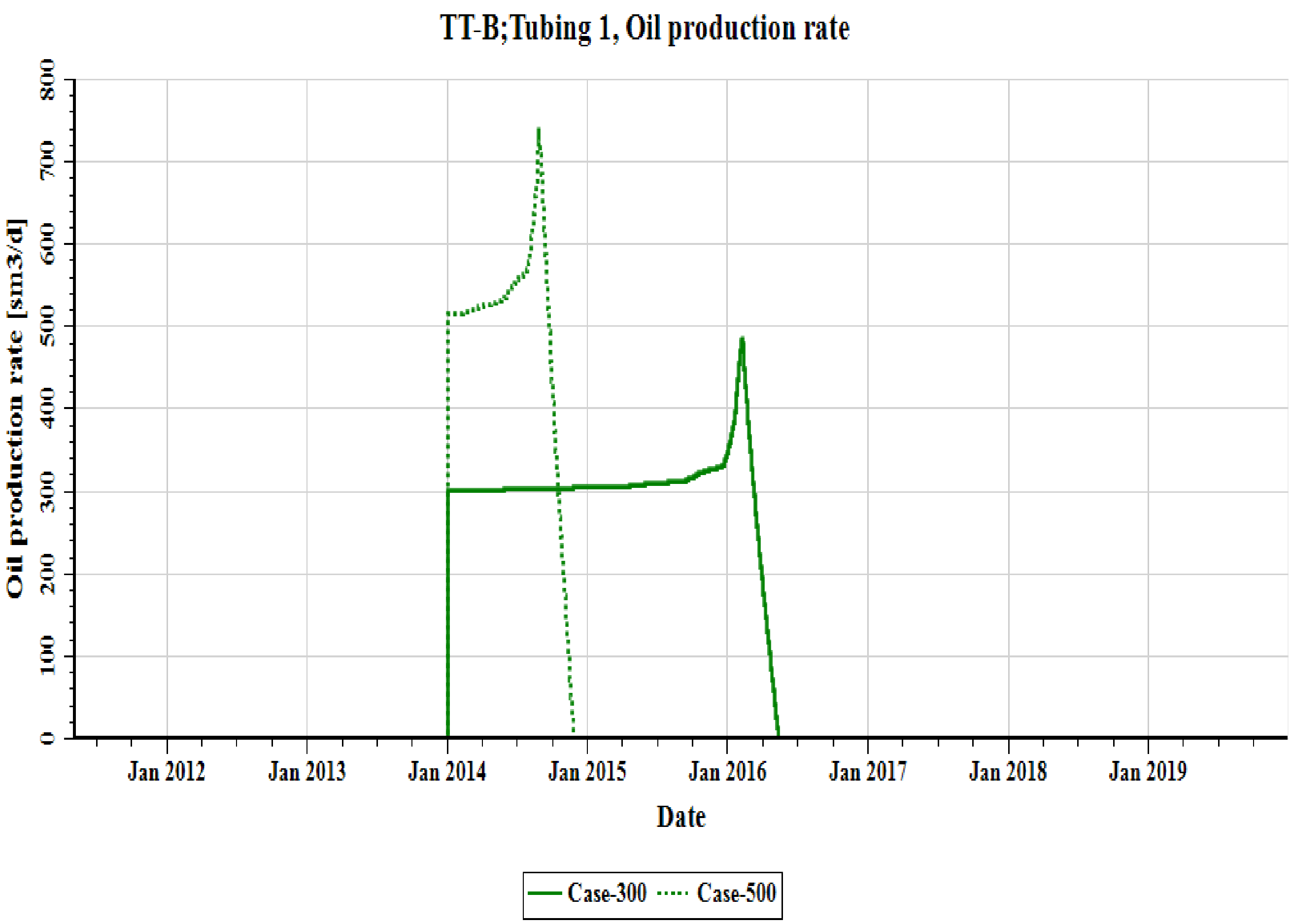


Figure 4.48 Results of prediction cases (Oil -TT-B)

The plot above 4.48 is showing the oil forecasting for two different cases for the TT-B (one of three suggested wells). The solid dark green line and the dotted dark green line are representing case-300 (less excessive production rate) and case-500 (more excessive production rate) respectively.

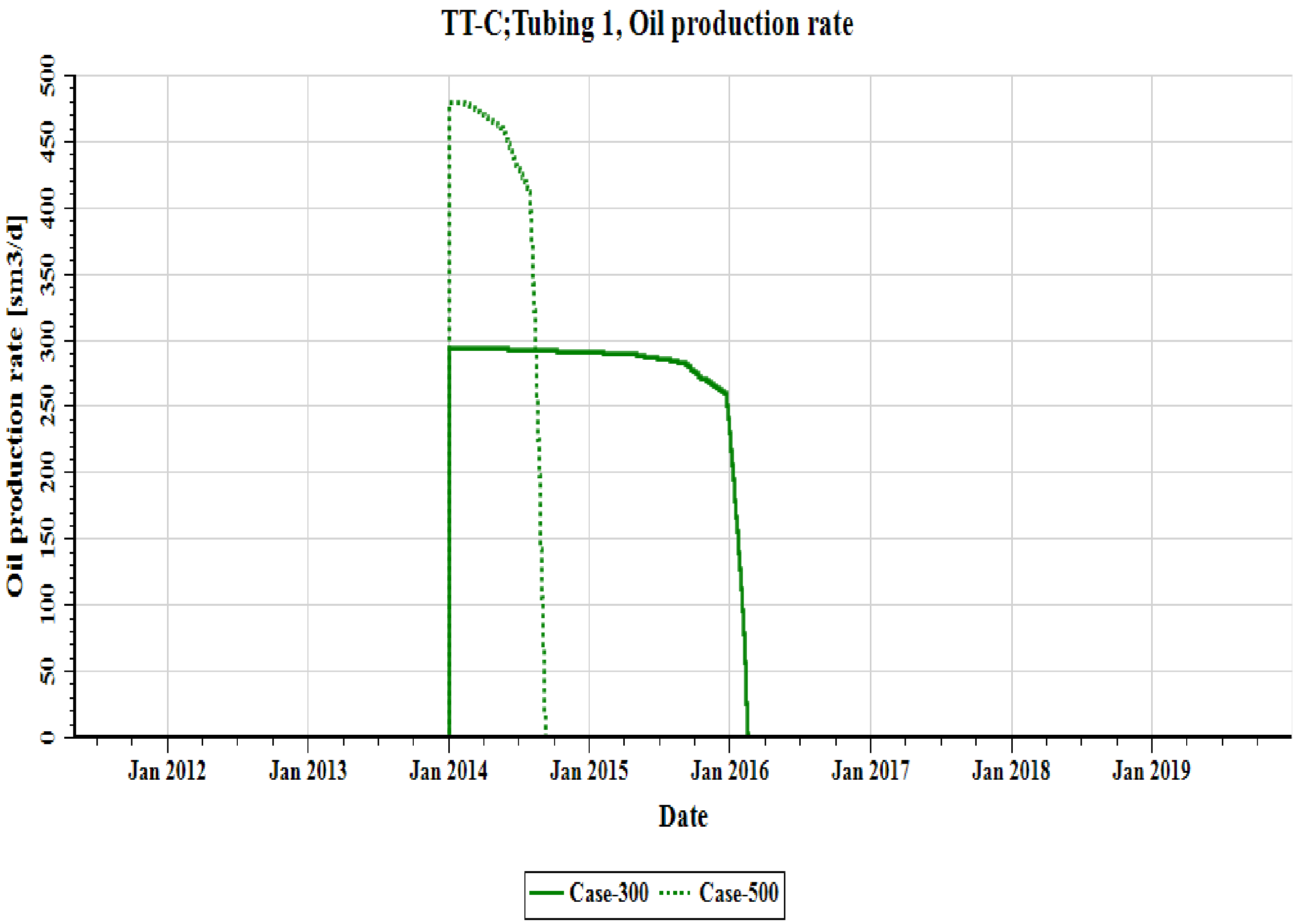


Figure 4.49 Results of prediction cases (Oil -TT-C)

The plot above 4.47 is showing the oil forecasting for two different cases for the TT-C (one of three suggested wells). The solid dark green line and the dotted dark green line are representing case-300 (less excessive production rate) and case-500 (more excessive production rate) respectively.

4.2.2 Wellhead and Bottom hole Pressure

As stated in table 4.1 the wellhead pressure was set to 10 bars as a limit which means that the well will stop producing when the wellhead pressure reached 10 bars. The flowing figures are showing the wellhead and the bottom hole pressure performance during the prediction period for each well and for the four prediction case scenarios.

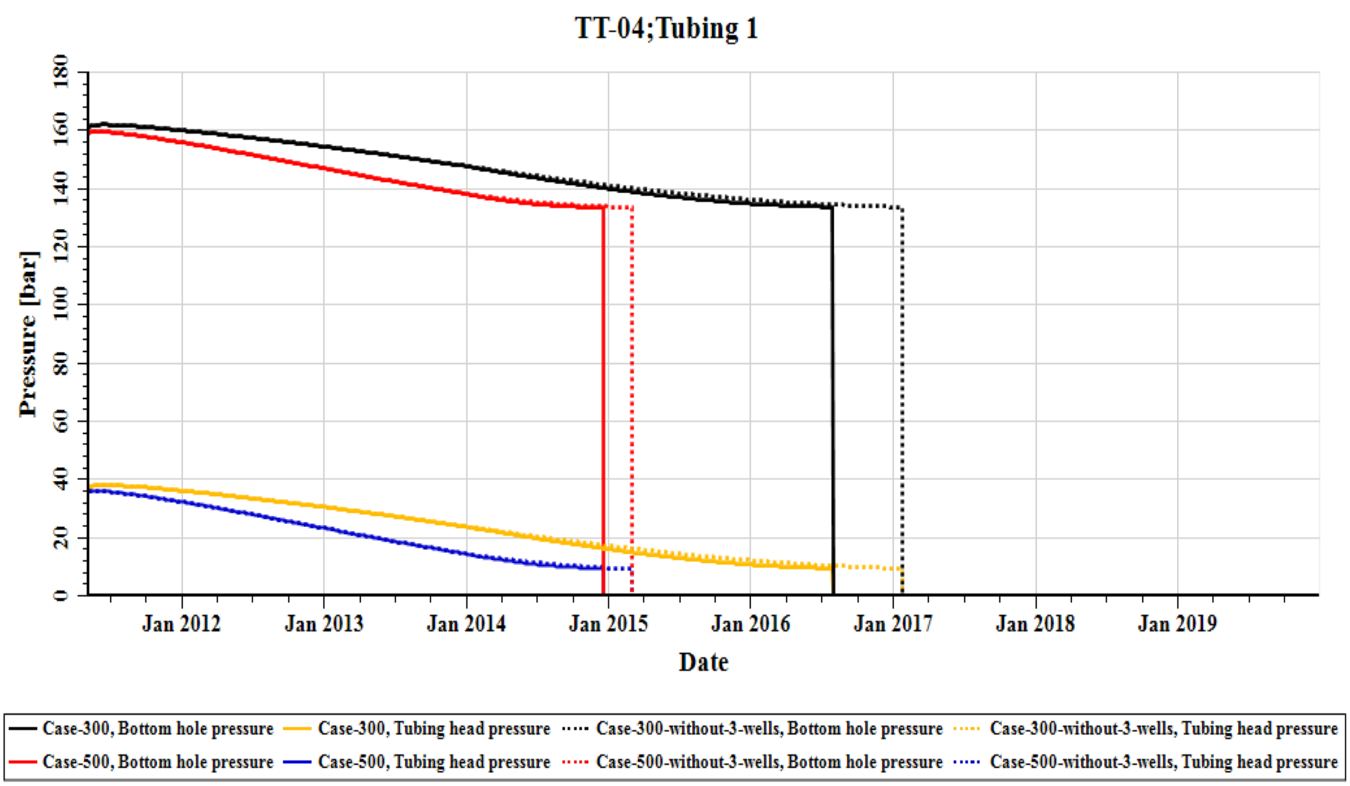


Figure 4.50 Results of prediction cases (Pressure-TT-04)

The plot above 4.50 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-04. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

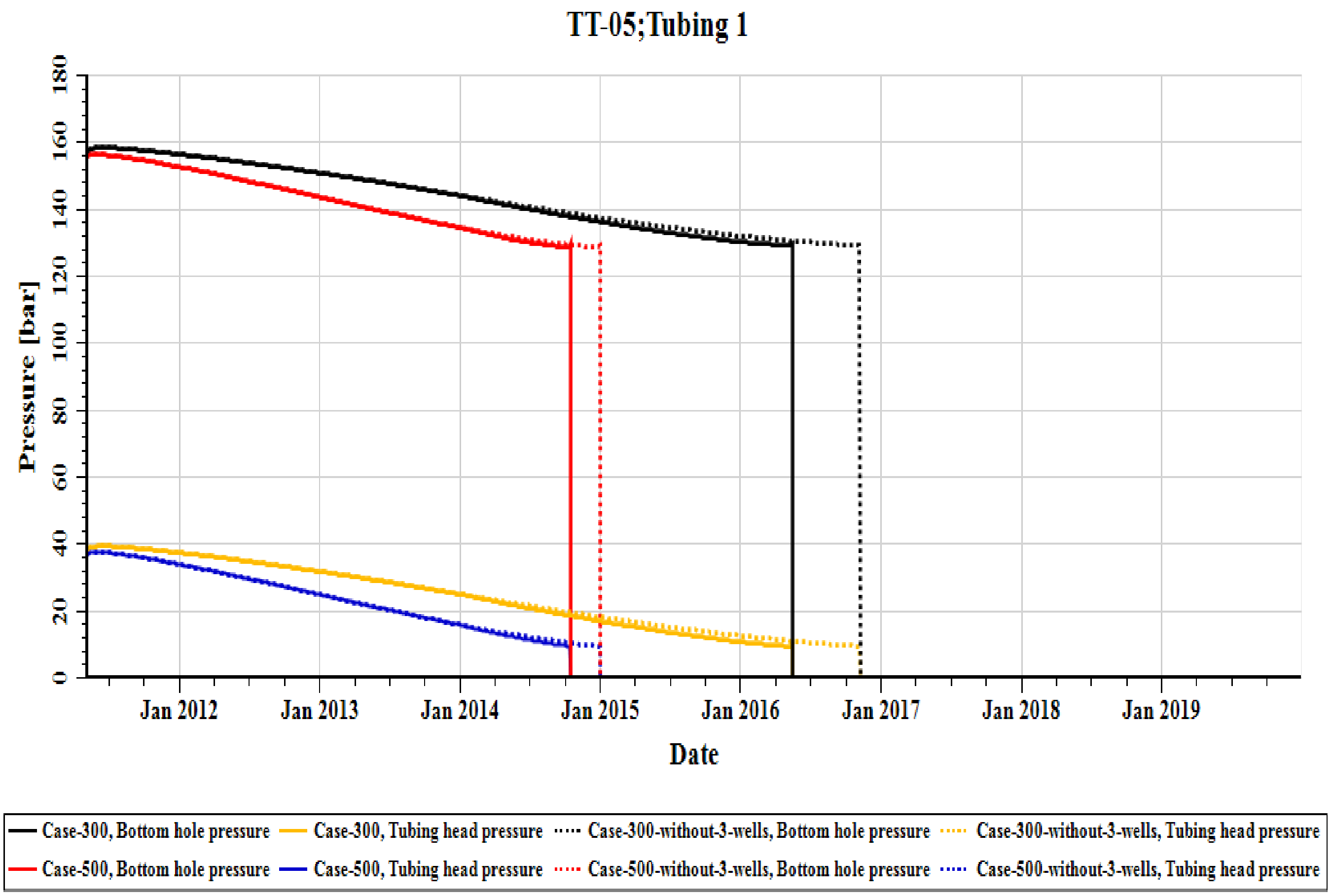


Figure 4.51 Results of prediction cases (Pressure-TT-05)

The plot above 4.51 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-05. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

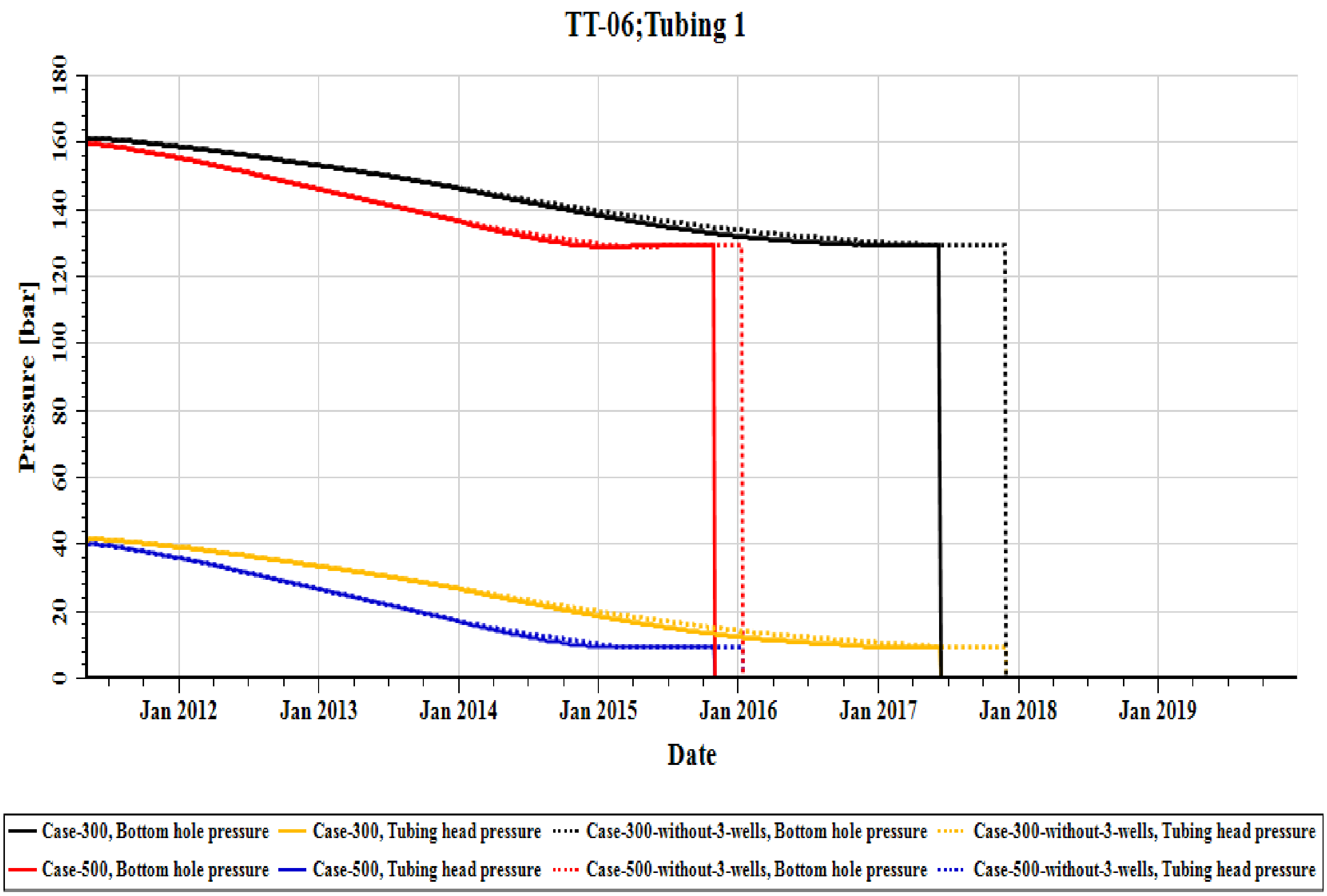


Figure 4.52 Results of prediction cases (Pressure-TT-06)

The plot above 4.52 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-06. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

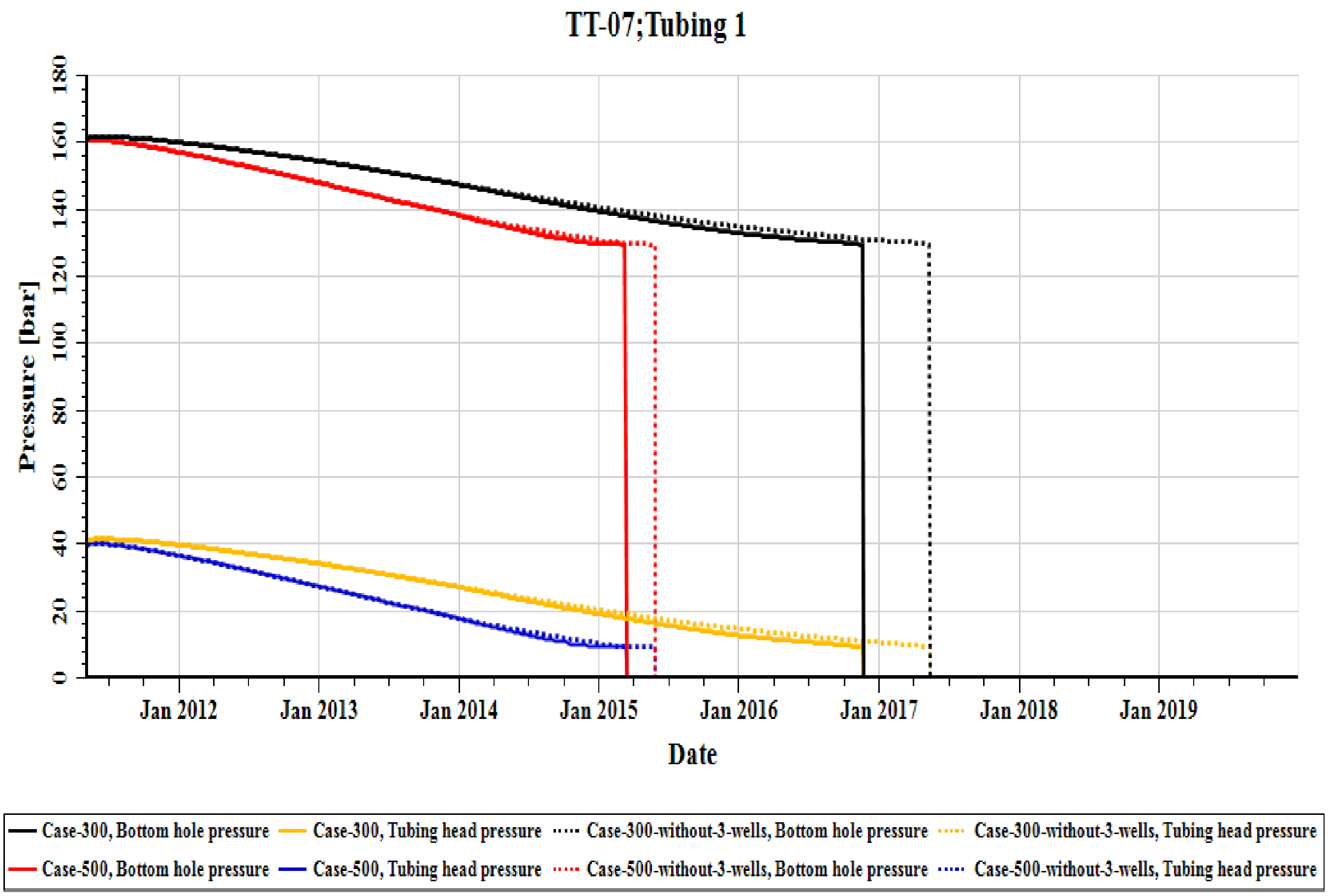


Figure 4.53 Results of prediction cases (Pressure-TT-07)

The plot above 4.53 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-07. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

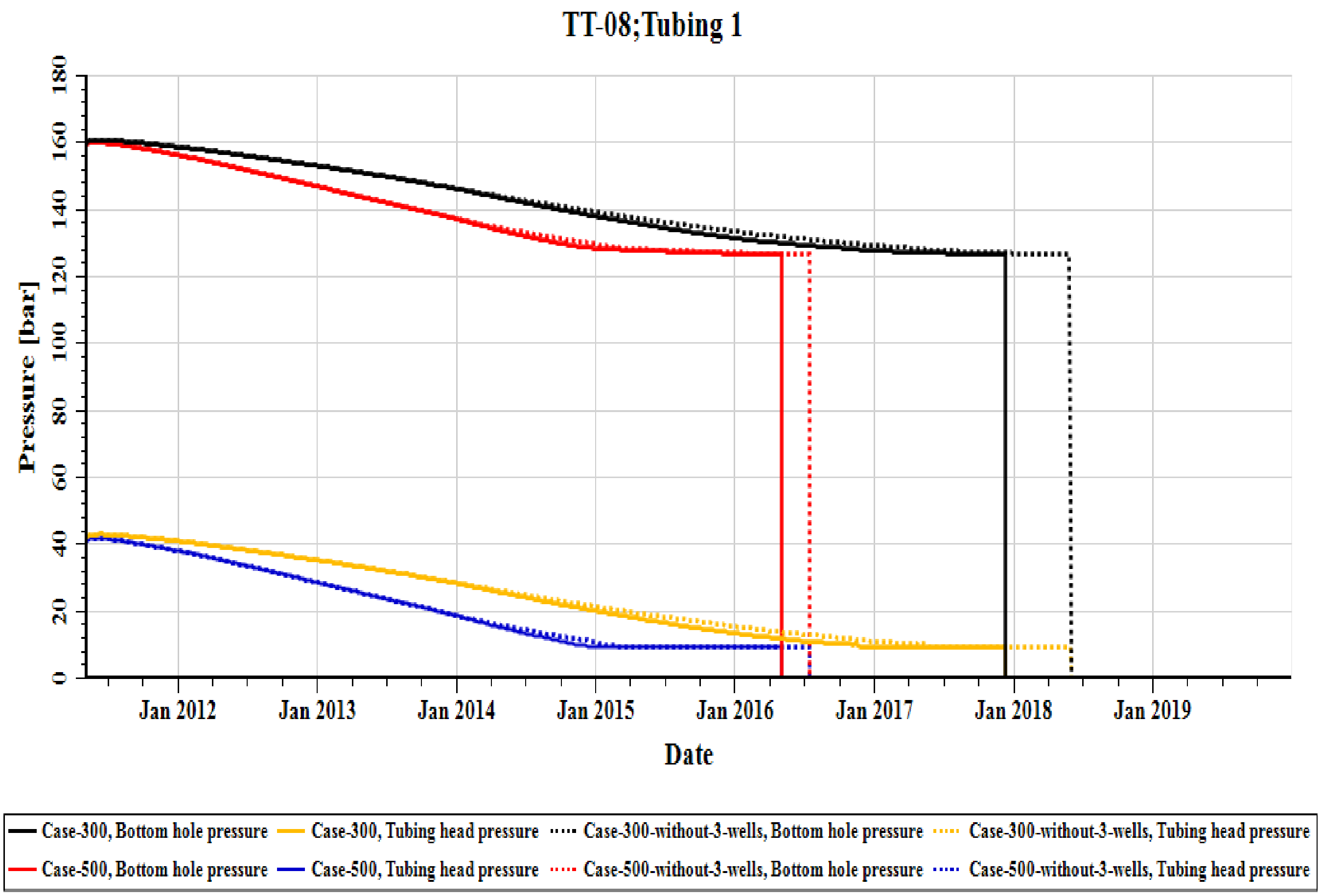


Figure 4.54 Results of prediction cases (Pressure-TT-08)

The plot above 4.54 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-08. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

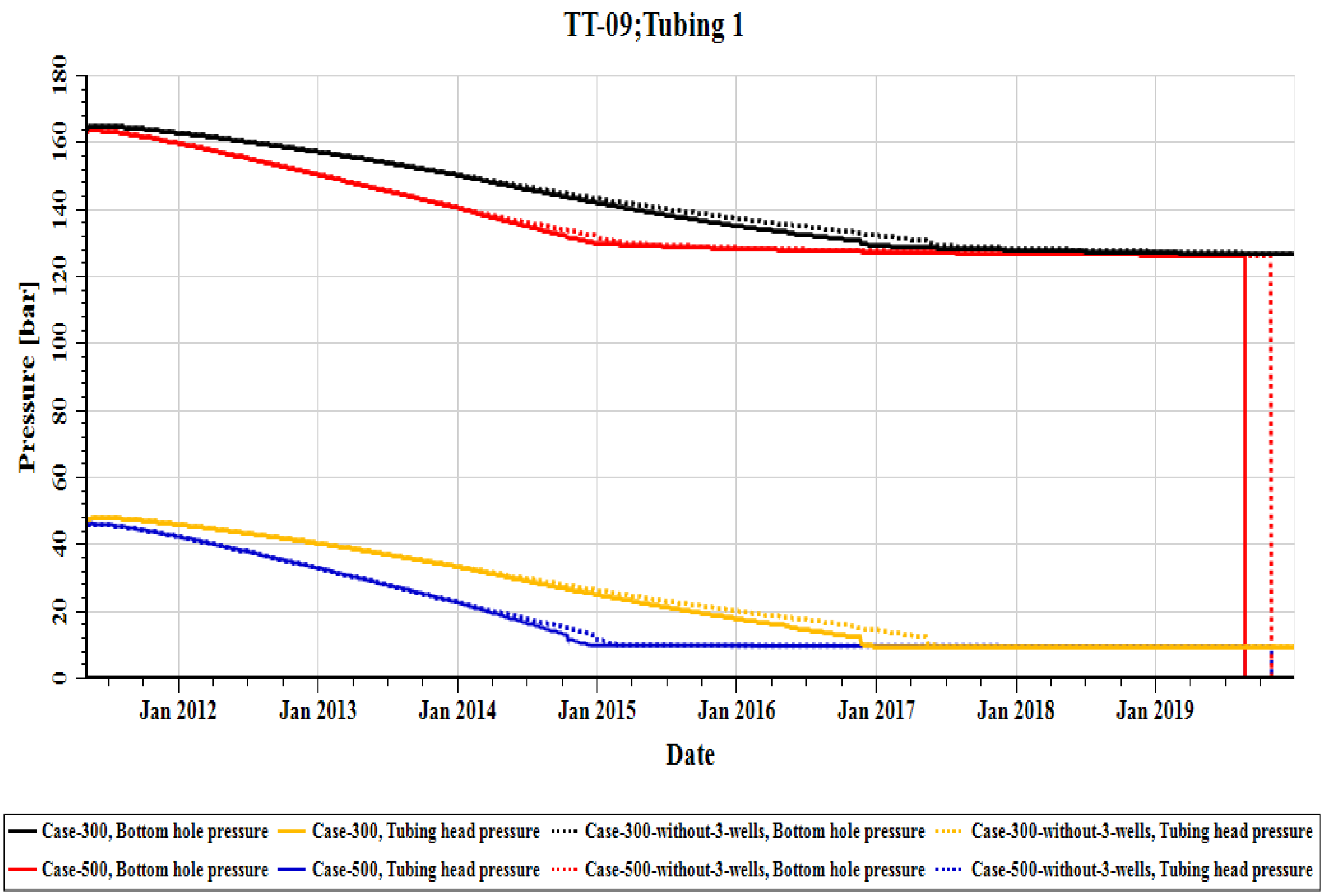


Figure 4.55 Results of prediction cases (Pressure-TT-09)

The plot above 4.55 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-09. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

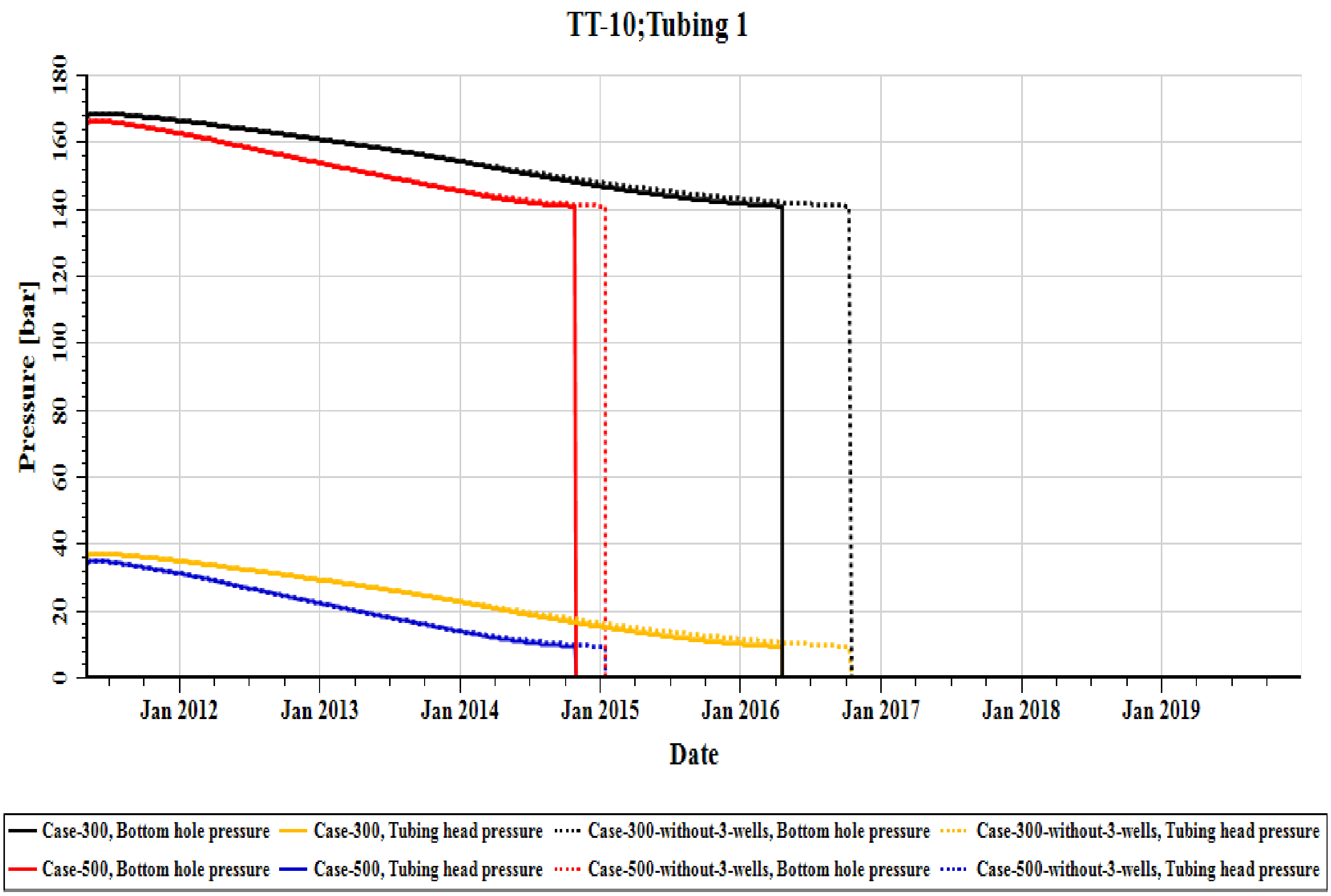


Figure 4.56 Results of prediction cases (Pressure-TT-10)

The plot above 4.56 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-10. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

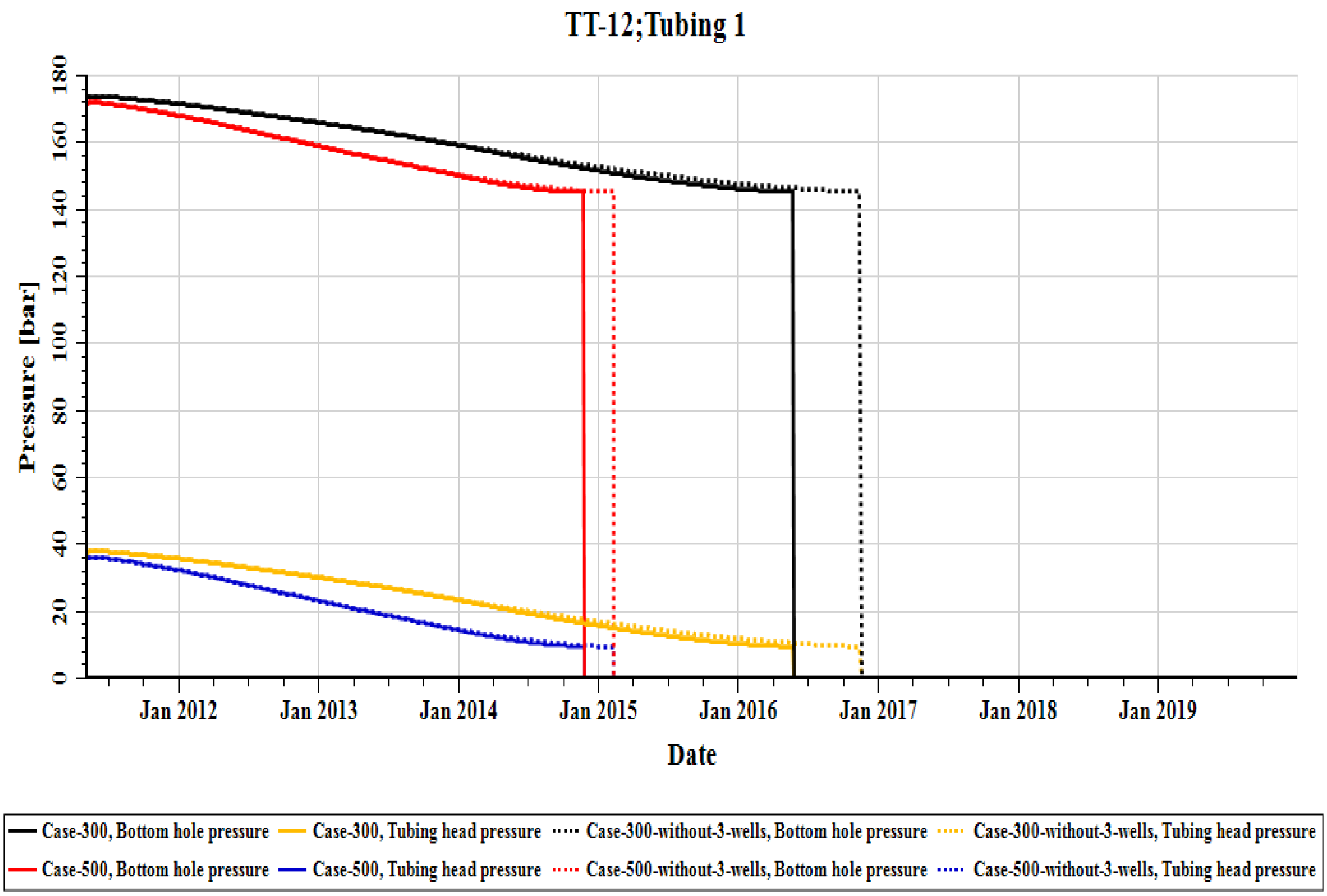


Figure 4.57 Results of prediction cases (Pressure-TT-12)

The plot above 4.57 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-12. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

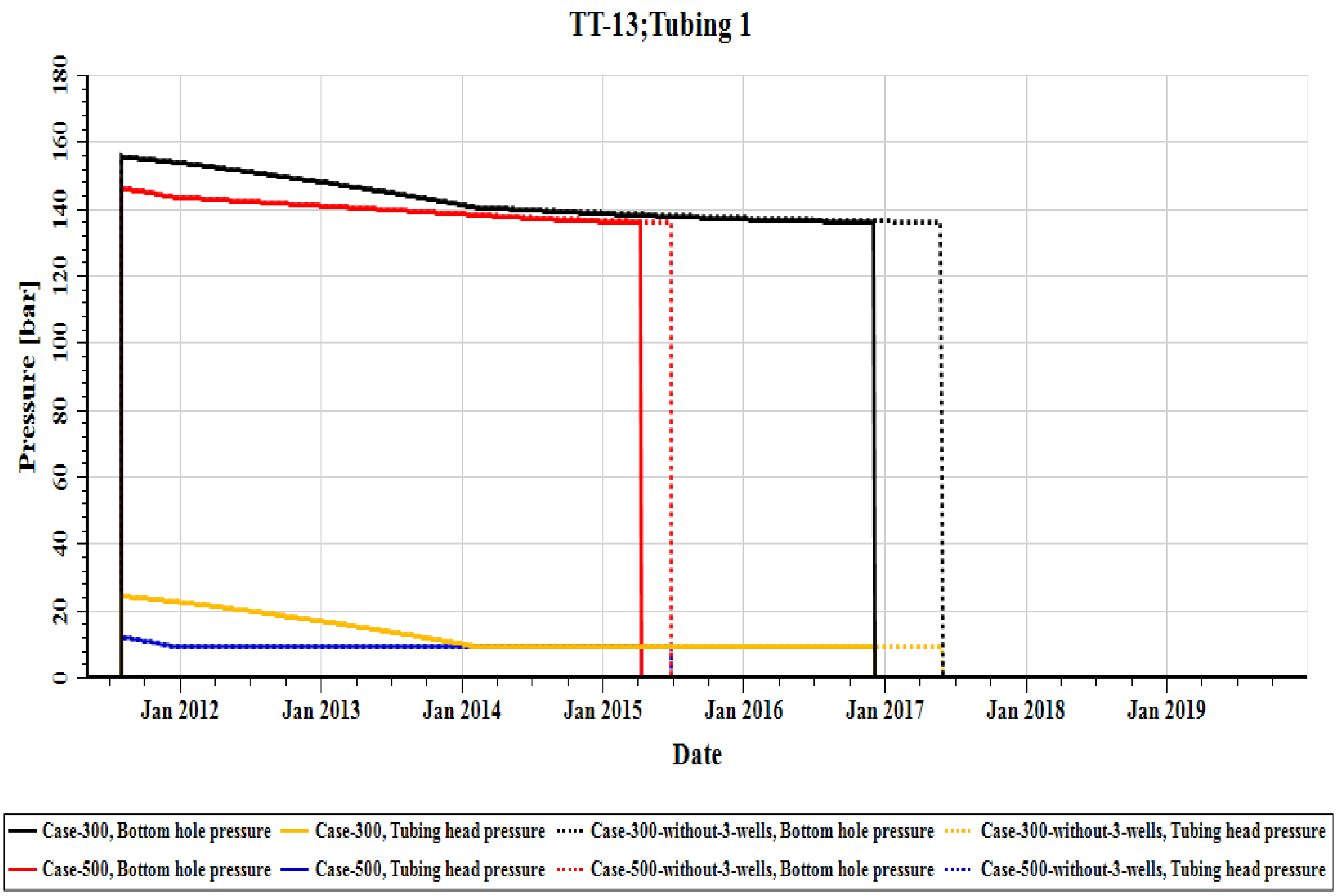


Figure 4.58 Results of prediction cases (Pressure-TT-13)

The plot above 4.58 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-13. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

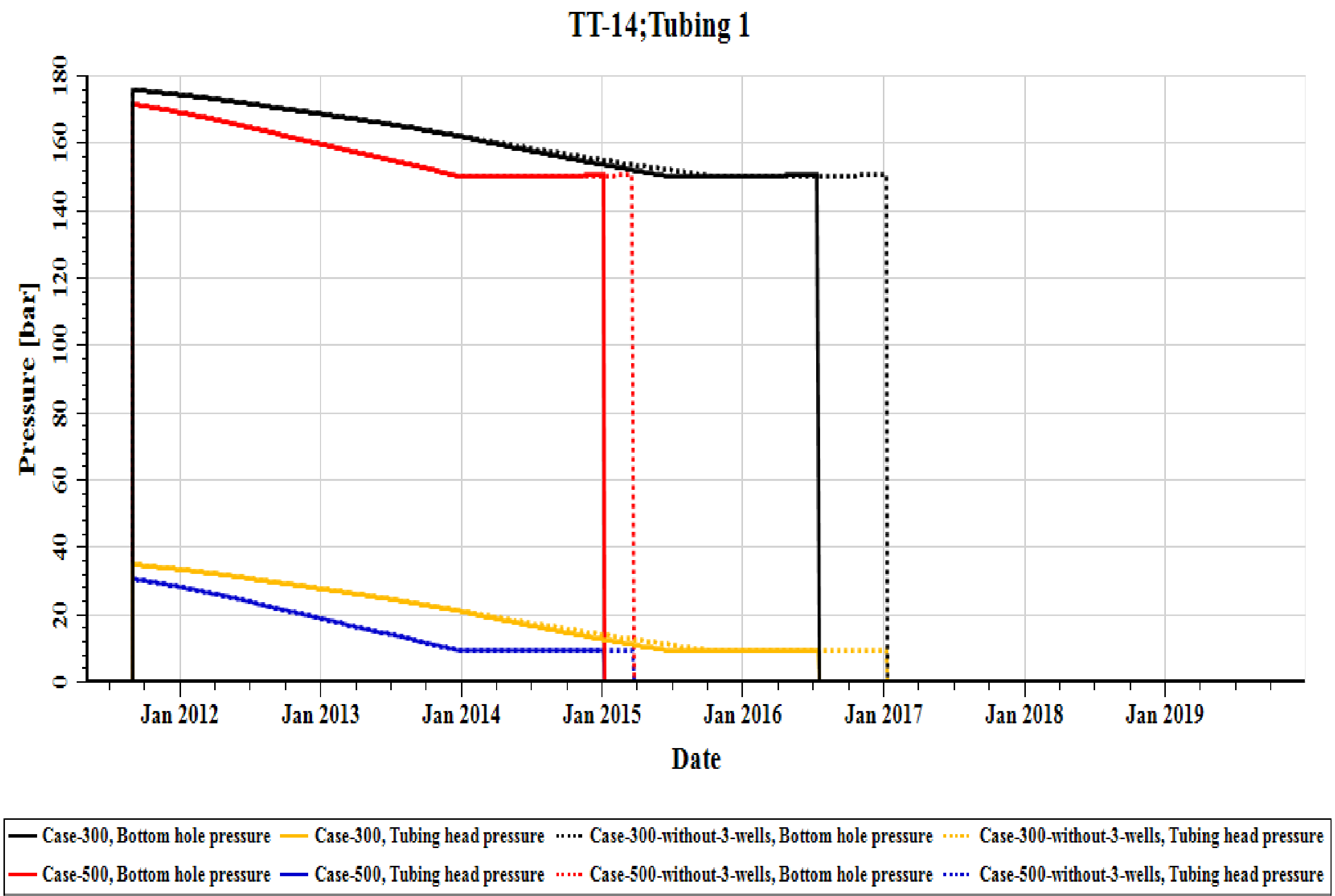


Figure 4.59 Results of prediction cases (Pressure-TT-14)

The plot above 4.59 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-14. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

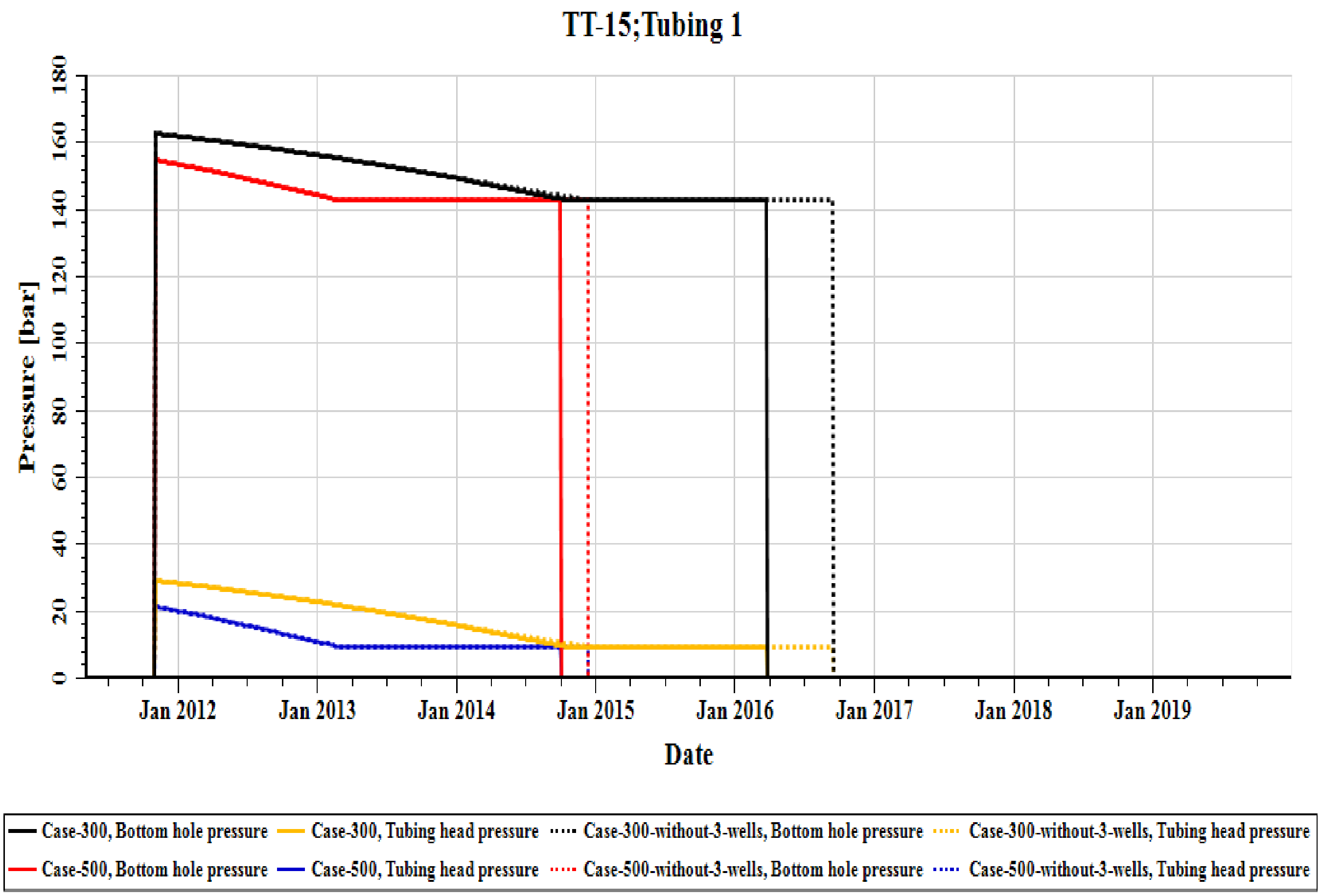


Figure 4.60 Results of prediction cases (Pressure-TT-15)

The plot above 4.60 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-15. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

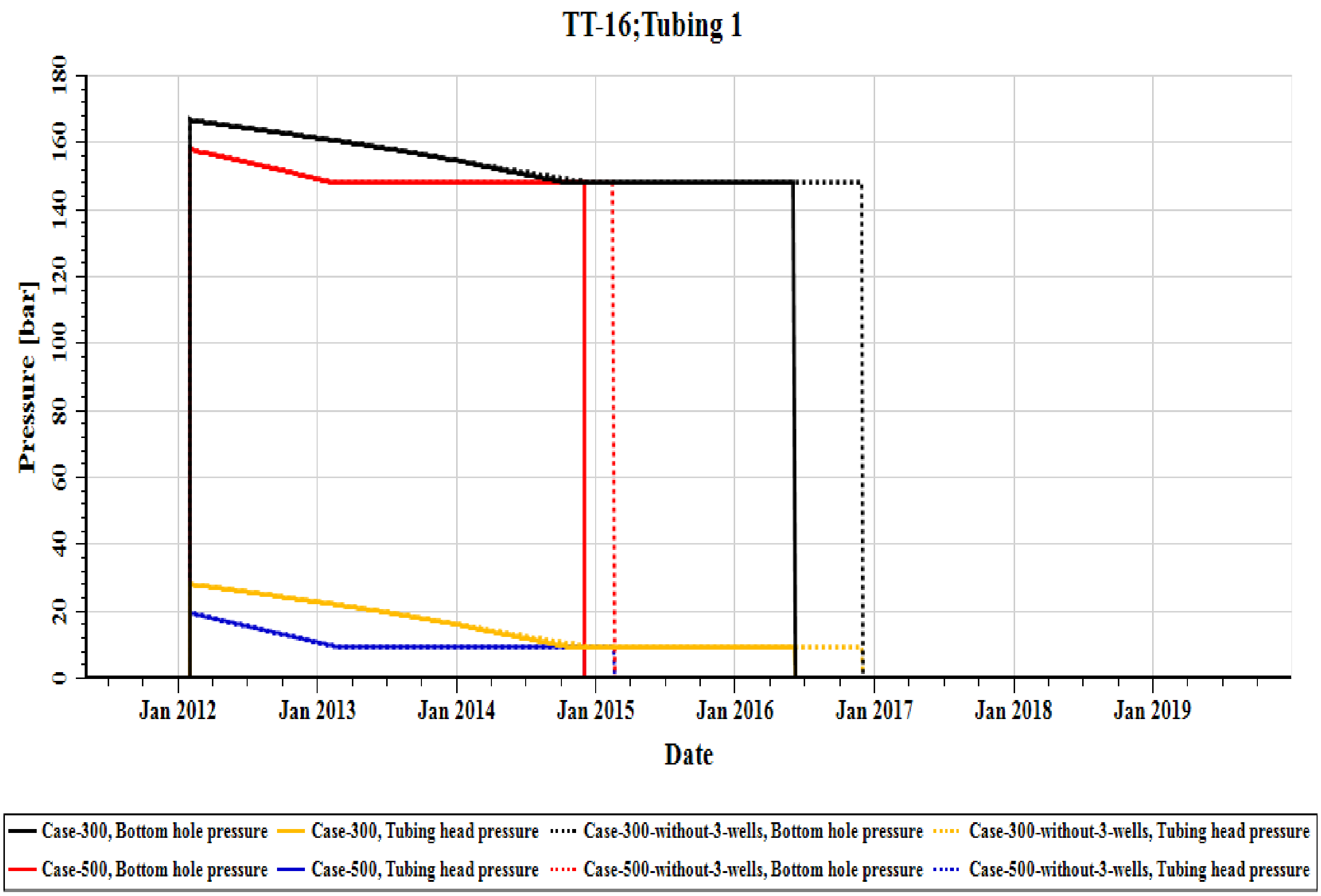


Figure 4.61 Results of prediction cases (Pressure-TT-16)

The plot above 4.61 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-16. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

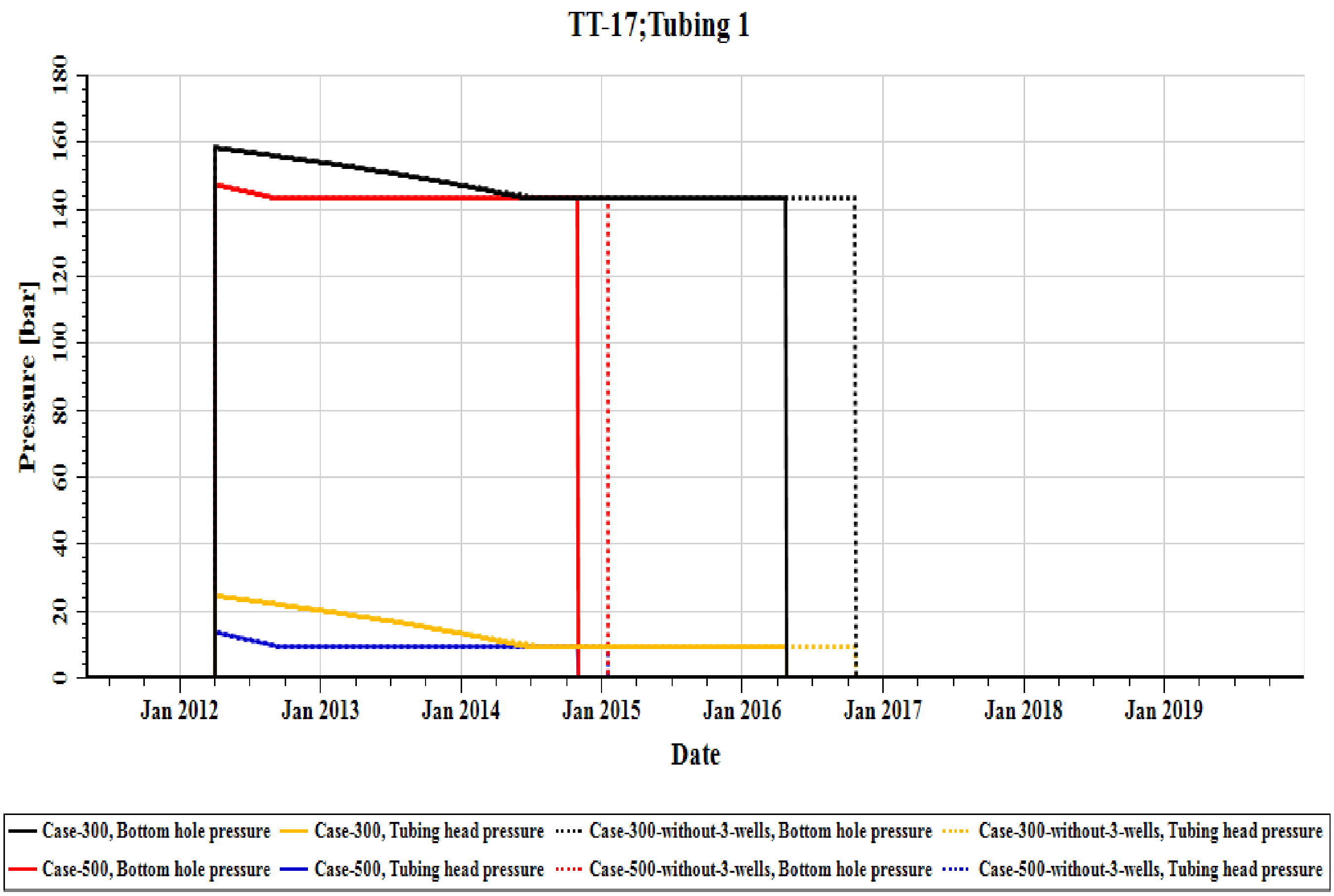


Figure 4.62 Results of prediction cases (Pressure-TT-17)

The plot above 4.62 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-17. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

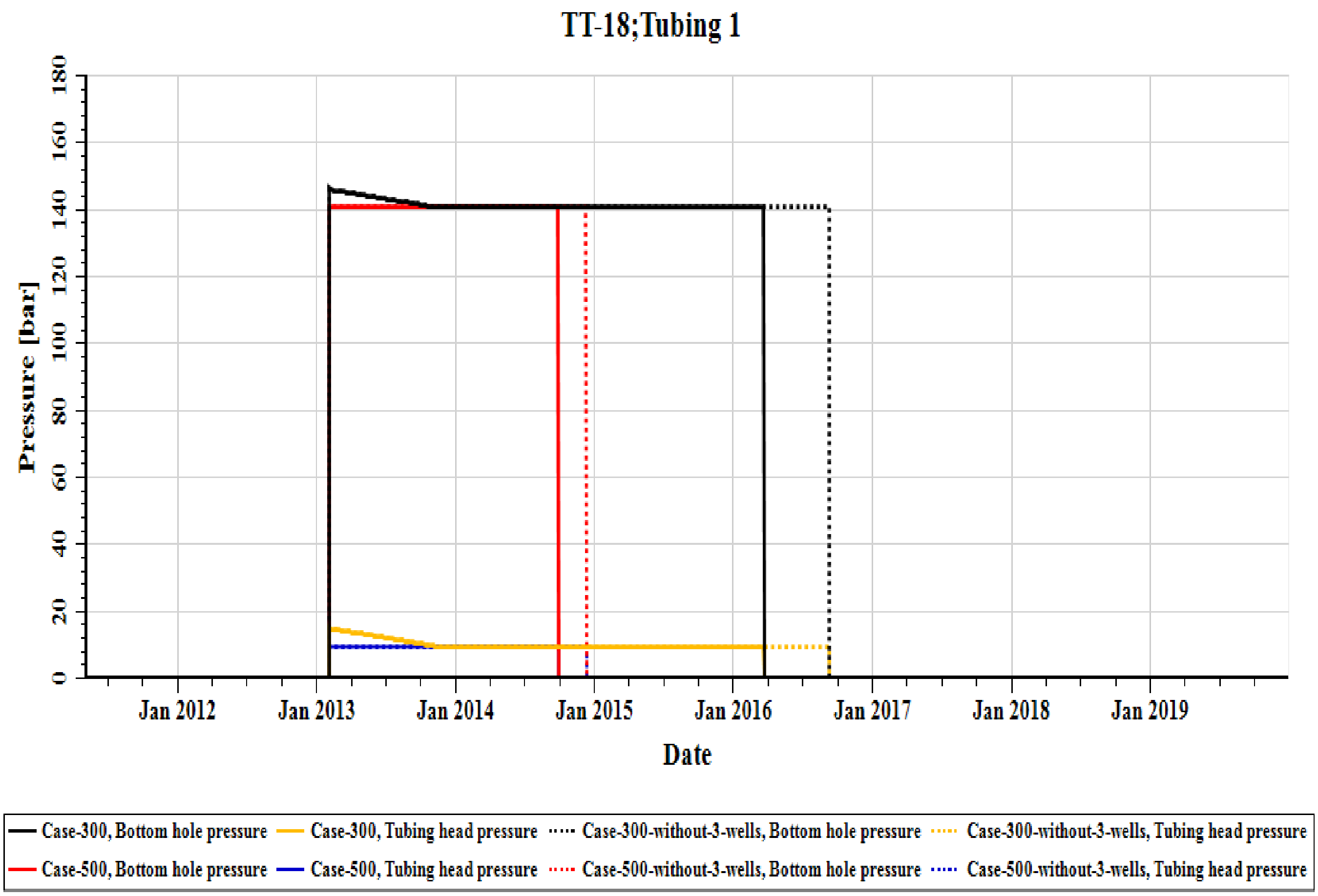


Figure 4.63 Results of prediction cases (Pressure-TT-18)

The plot above 4.63 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-18. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

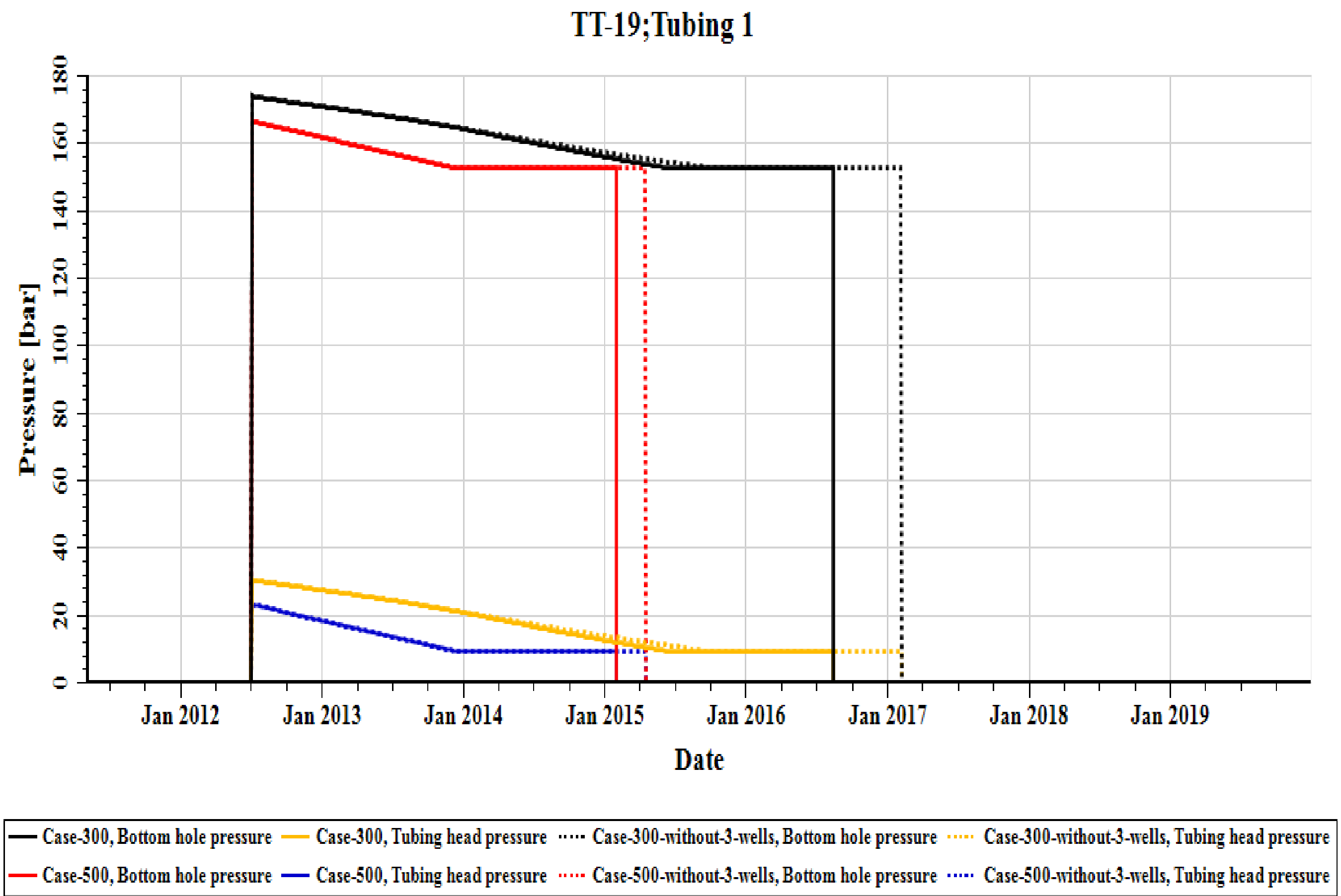


Figure 4.64 Results of prediction cases (Pressure-TT-19)

The plot above 4.64 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-19. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

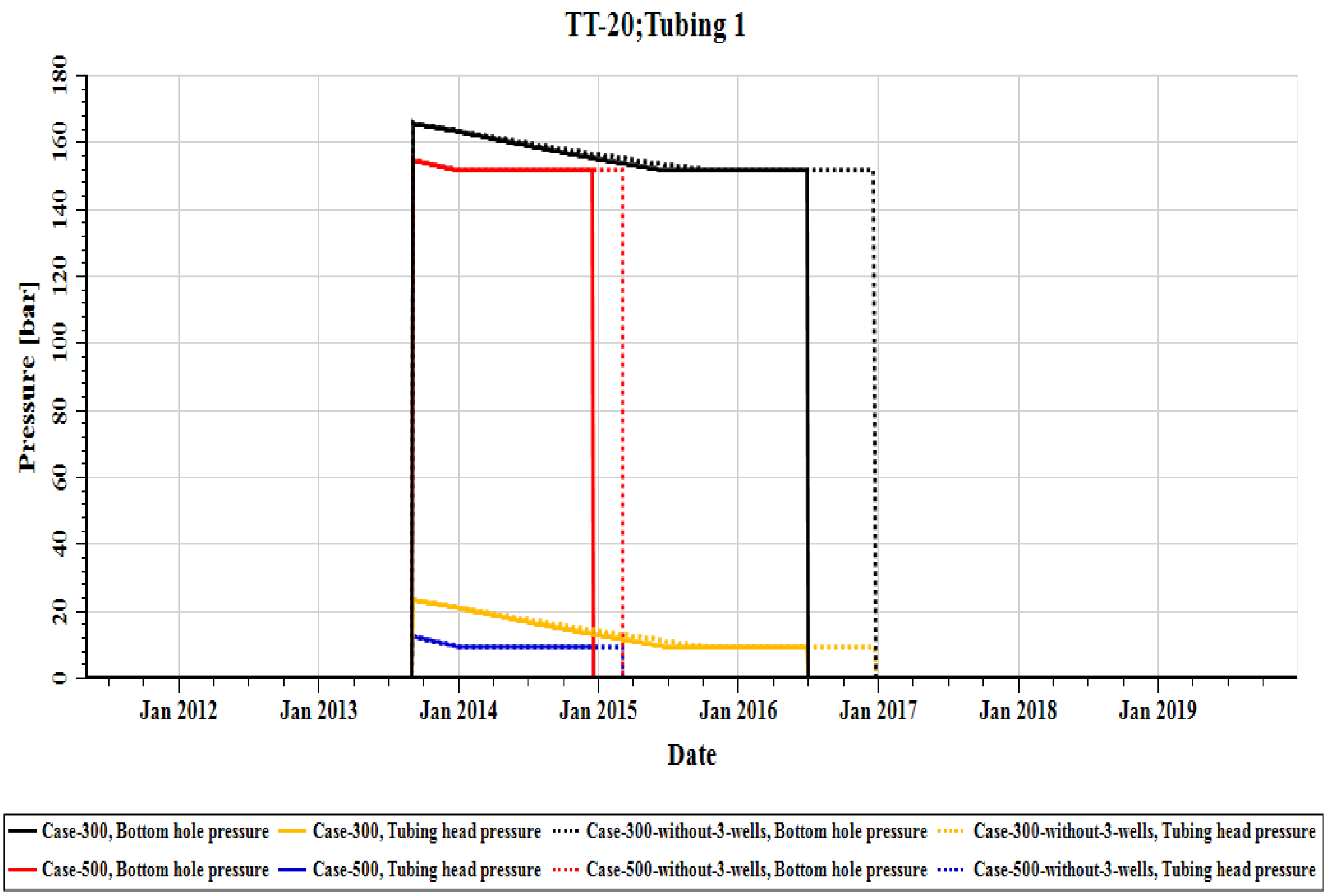


Figure 4.65 Results of prediction cases (Pressure-TT-20)

The plot above 4.65 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-20. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

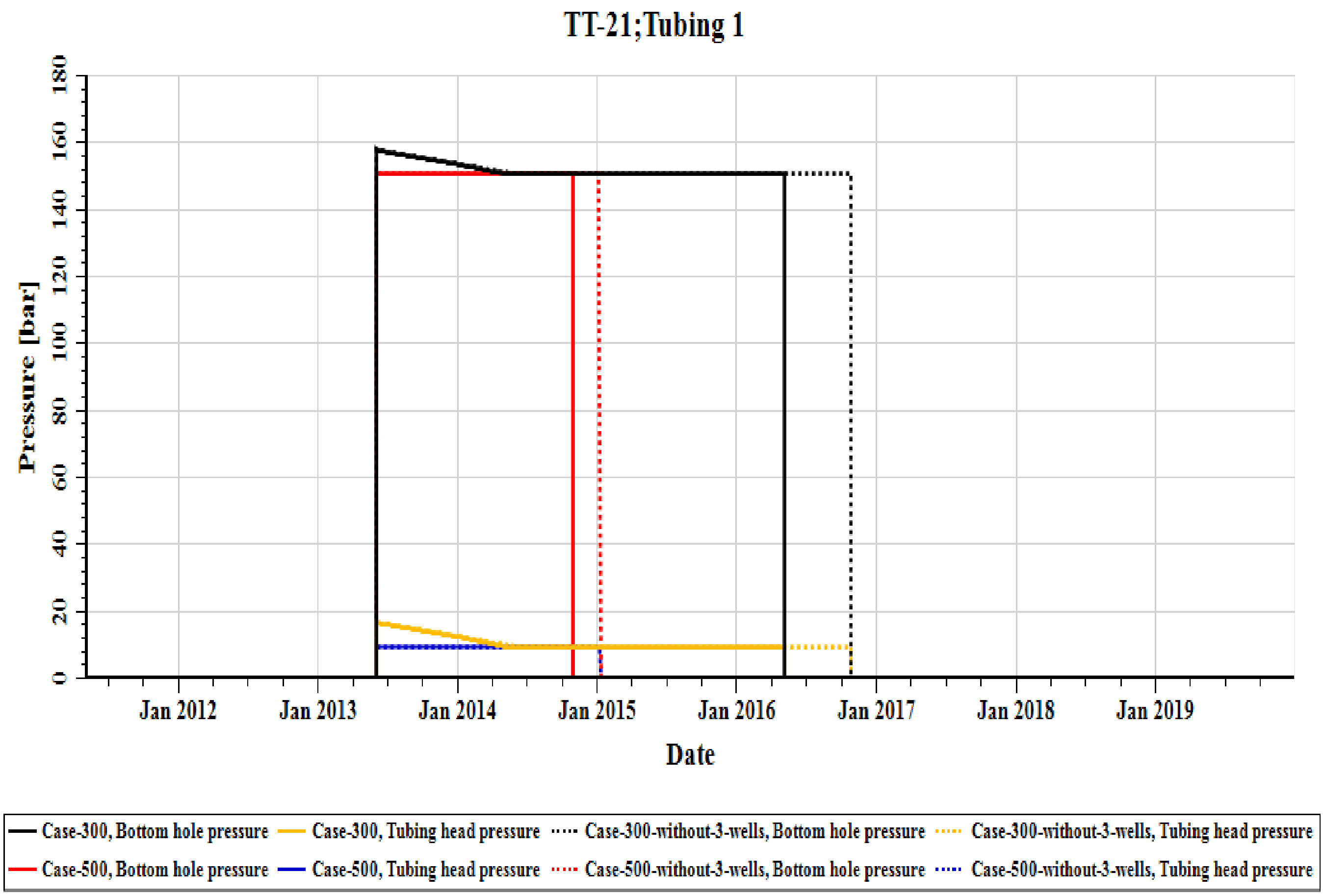


Figure 4.66 Results of prediction cases (Pressure-TT-21)

The plot above 4.66 is showing the wellhead and bottom hole pressure performance for four different prediction cases of TT-21. The solid orange and dotted orange lines are representing the well head pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid blue and dotted blue lines are representing the well head pressure performance for the cases 500 and Case 500 without 3 wells respectively. The solid black and dotted black lines are representing the bottom hole pressure performance for the cases 300 and Case 300 without 3 wells respectively whereas the solid red and dotted red lines are representing the bottom hole pressure performance for the cases 500 and Case 500 without 3 wells respectively.

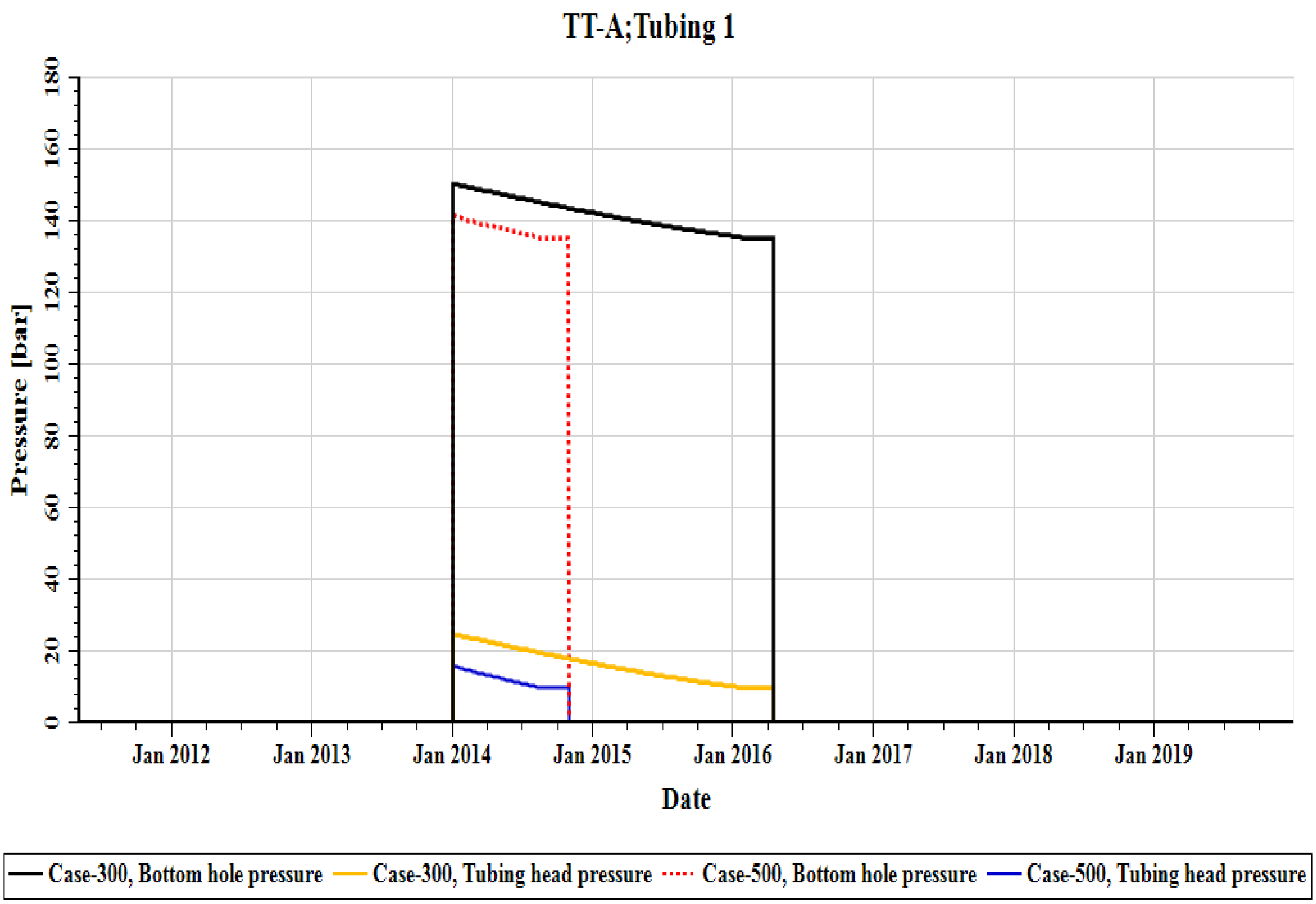


Figure 4.67 Results of prediction cases (Pressure-TT-A)

The plot above 4.67 is showing the wellhead and bottom hole pressure performance for two different prediction cases of TT-A (which is one of the three suggested wells). The solid orange line is representing the well head pressure performance for the cases 300 whereas the solid blue line is representing the well head pressure performance for the cases 500. The solid black line is representing the bottom hole pressure performance for the cases 300 whereas the dotted red line is representing the bottom hole pressure performance for the cases 500.

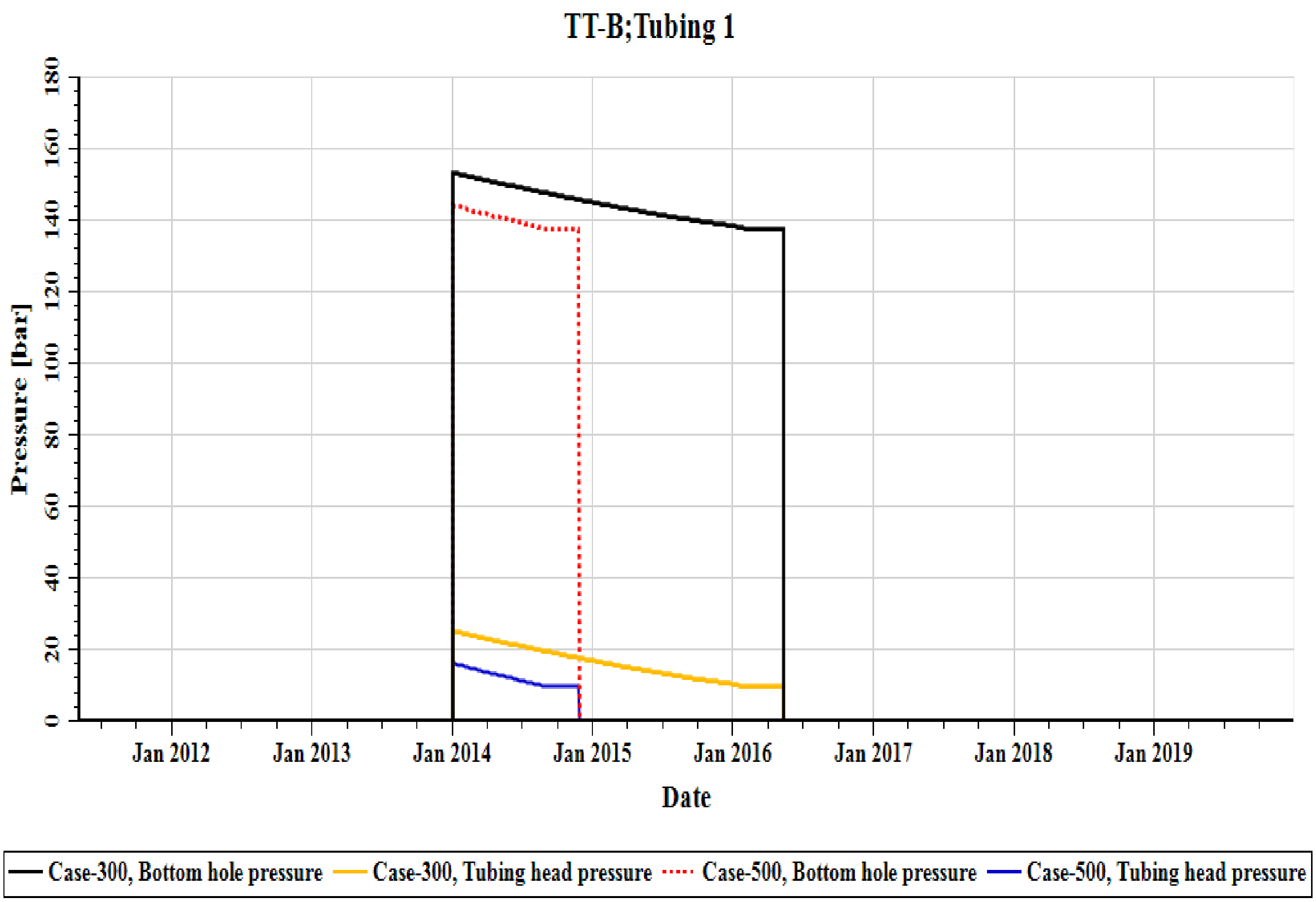


Figure 4.68 Results of prediction cases (Pressure-TT-B)

The plot above 4.68 is showing the wellhead and bottom hole pressure performance for two different prediction cases of TT-B (which is one of the three suggested wells). The solid orange line is representing the well head pressure performance for the cases 300 whereas the solid blue line is representing the well head pressure performance for the cases 500. The solid black line is representing the bottom hole pressure performance for the cases 300 whereas the dotted red line is representing the bottom hole pressure performance for the cases 500.

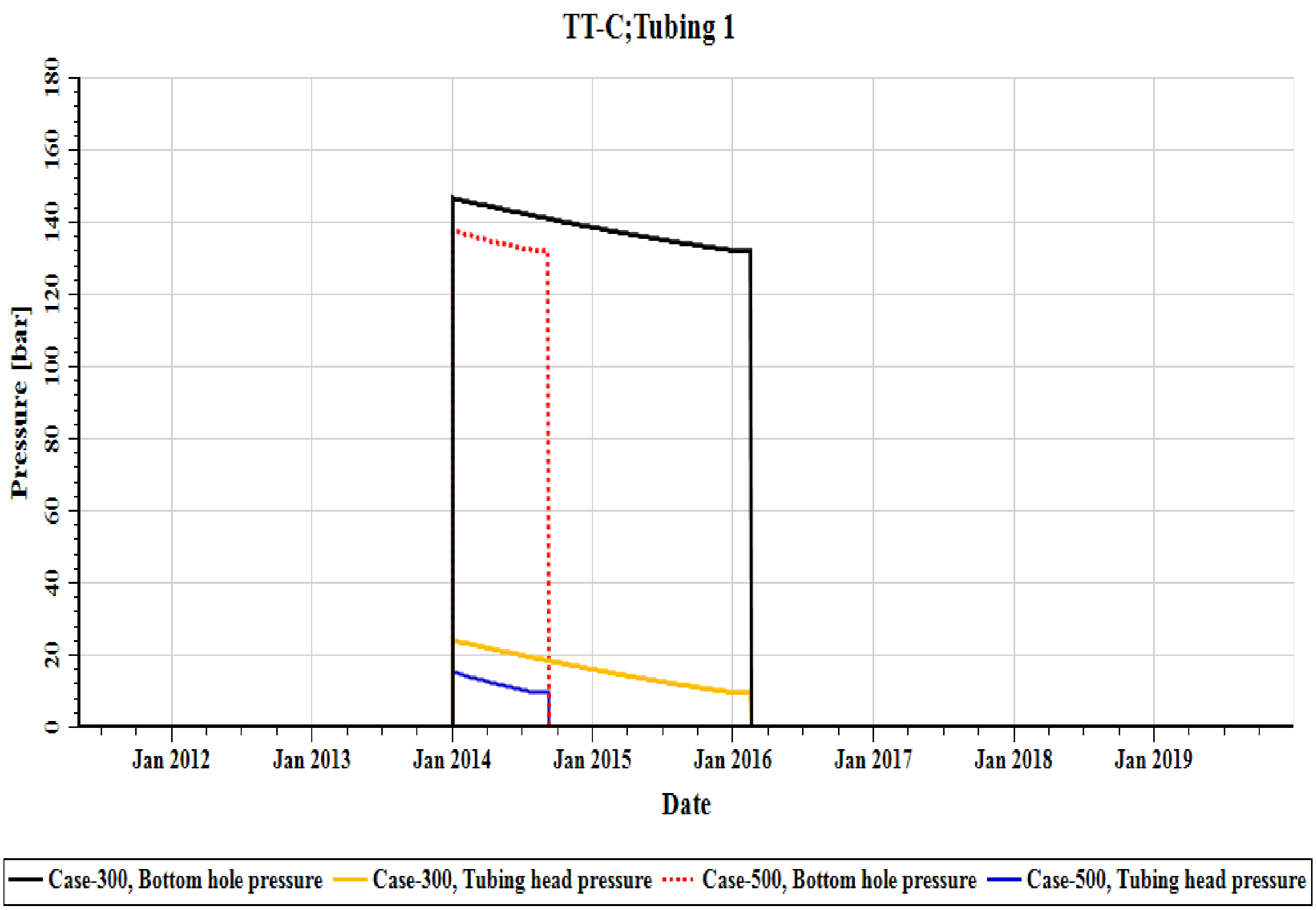


Figure 4.69 Results of prediction cases (Pressure-TT-C)

The plot above 4.69 is showing the wellhead and bottom hole pressure performance for two different prediction cases of TT-C (which is one of the three suggested wells). The solid orange line is representing the well head pressure performance for the cases 300 whereas the solid blue line is representing the well head pressure performance for the cases 500. The solid black line is representing the bottom hole pressure performance for the cases 300 whereas the dotted red line is representing the bottom hole pressure performance for the cases 500.

4.3 Criteria for selecting the new well locations

It was not an easy task to determine the new well locations at all specially in such complicated reservoir. Fortunately the software or the simulation allows the reservoir engineers to find the optimum location of the new well before drilling it in reality which is absolutely helpful in reducing the costs. As mentioned and presented in the chapters before, the reservoir properties distribution like matrix porosity, matrix permeability, fracture intensity, fracture porosity, fracture permeability and the connection among them are not uniform in the entire model. Shiranish formation has been divided into 10 layers and Kometan formation into 5 layers and in total there are 15 layers with different property distribution. Here the suggested well in a certain location penetrate the 15 layers which not necessarily all the penetrated grid cells by the well in the model may have the desired property. So locations with highest possible desired property distribution have been selected in combination with the performance of the other existing wells in terms of the actual and simulated production data and less pressure drop. Other criteria like avoiding early water production (far from TT-09 which was the first well produced water) and less reservoir thickness (in which the fracture intensity will be higher and improve the permeability).

4.4 Comparison of the simulated prediction data with the actual produced data

The operator in the Taq Taq oil field has announced in their official website that the total oil production rate till the end of 2017 was 206 million barrel. The cumulative oil production rate in the simulated prediction scenarios in this research has been estimated to about 80 million barrel till the end of 2017. Figure 6.70 is showing the cumulative oil production rates for the four prediction scenarios. The difference is about 126 million barrel. The reader will not be astonished after knowing the following facts which explain why there is such difference.

1. Taq Taq oil field started to produce since 2002. Till 23rd May 2010 Taq Taq oil field produced more than 10 million barrel which can be added to the estimation of this research.
2. As mentioned from the beginning of this research, Taq Taq oil field consists of two pay zones which one of them is about 600 meters deep and contains 6 wells (TT-11, TT-25, TT-26, TT-30 and TT-31). By adding the amount of oil which has been produced from this zone the difference will be less.
3. There are 6 other wells (TT-22, TT-23, TT-24, TT-27, TT-28 and TT-29) which producing from Shiranish and Kometan formation didn't contribute due to the lack of data. Knowing the amount of the oil produced from the mentioned wells will make the difference less.
4. It is very important to say that the estimation in this research comprise the amount of the oil which produced (flowed to the surface) naturally and without any artificial lift. Knowing the amount of the oil which produced by artificial lift will make the difference less again.

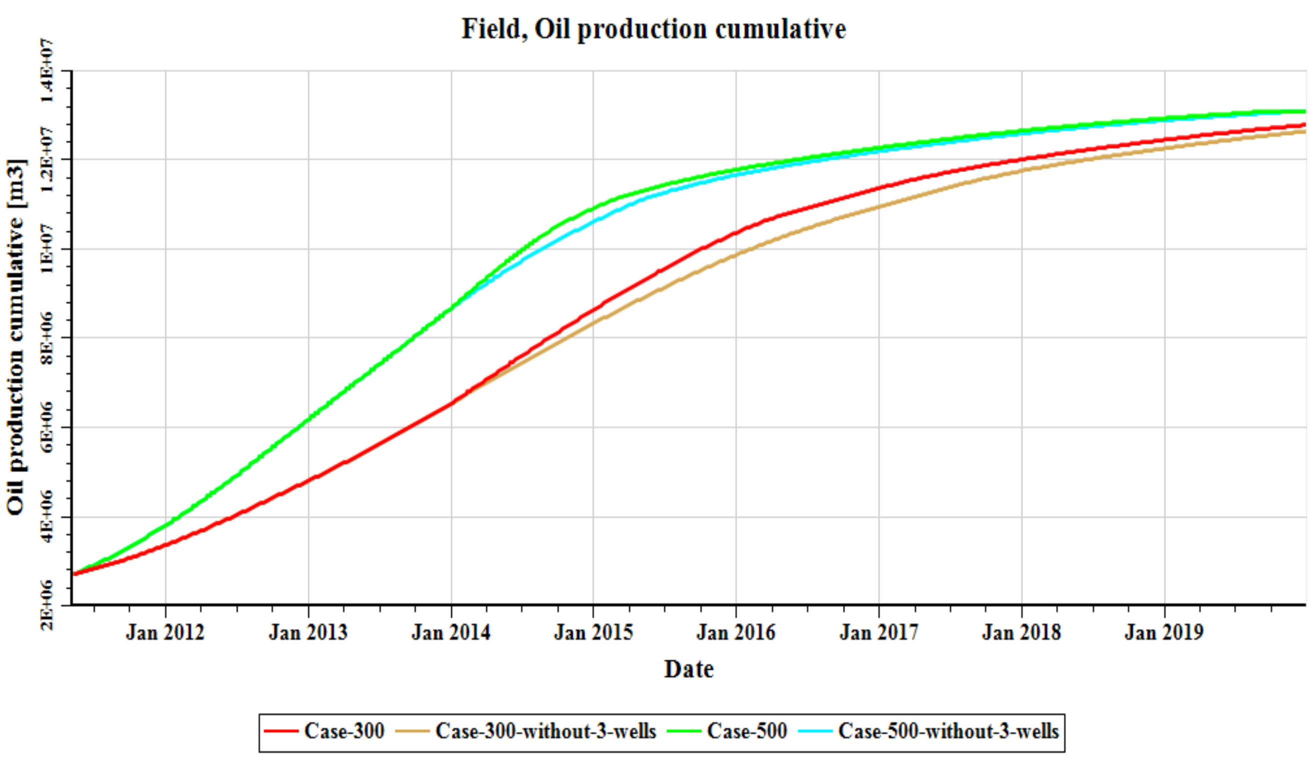


Figure 4.70 The Cumulative Oil Production Rate

4.5 Effect of the gas injection on the recovery

The fifth prediction case scenario has been run to show the effect of the gas injection on recovery. Case-500 has been re-run again in which the three suggested production wells have been converted to gas injectors. The prediction case started from May 6th 2011 till the end of 2019. The three suggested gas injectors started to inject gas since January 1st 2014. Figure 4.71 is showing the effect of the gas injection.

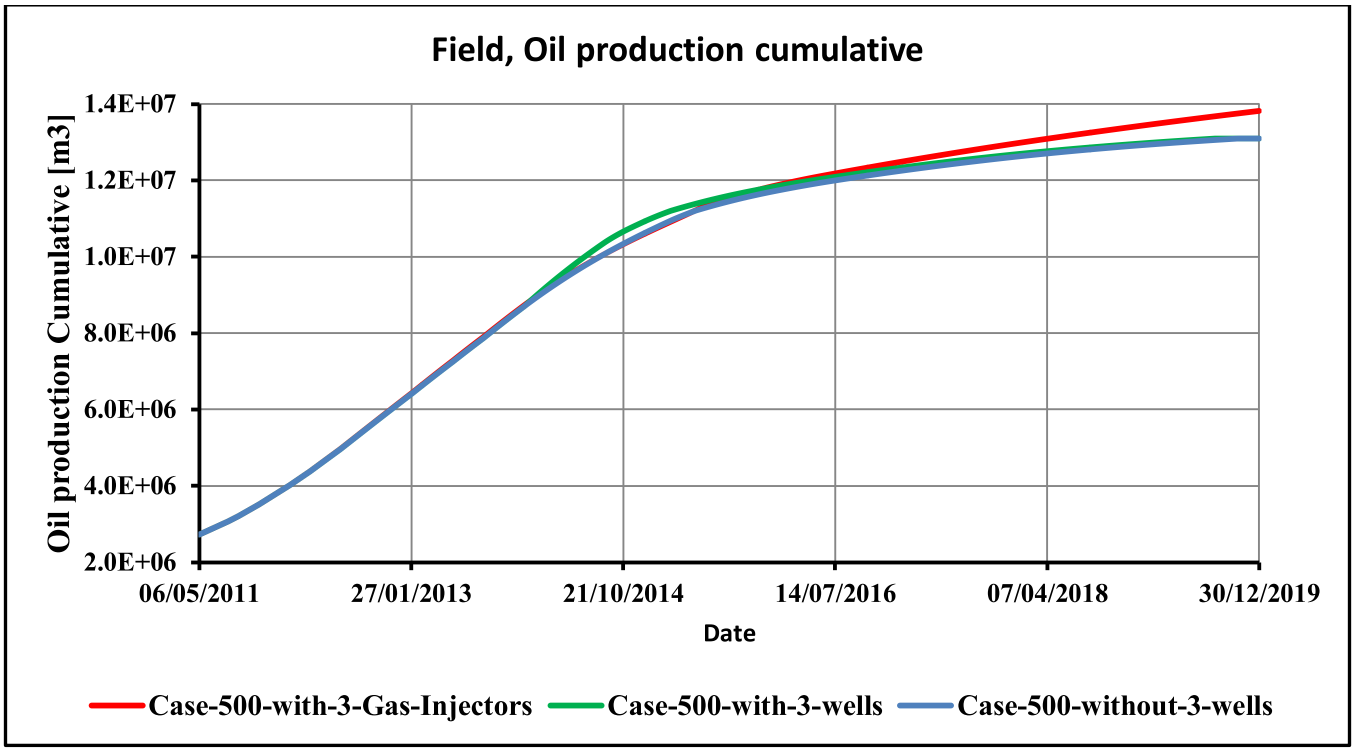


Figure 4.71 The gas injection effect on recovery

5. Conclusions and recommendations

5.1 Conclusions

Reservoir simulation is very important to understand the reservoir better. A reliable three dimensional geological model is required for prediction and knowing the reservoir performance in the future. One of the main goals of this investigation was to find a proper method to develop and manage the oil field to produce for longer period and increasing the recovery. To do so, the model has been validated via the history matching process, two different oil rates have been selected as a target in conjunction with wellhead pressure as a limit and three new well locations are proposed.

History matching process has been conducted to validate the model and make it reliable for prediction. Two history matching simulation cases have been presented in this investigation. In both simulation cases the oil rates have been matched very well for the field and also for each well alone. The matched case for the gas production rates has been achieved by reducing the value of the bubble point pressure which ultimately reduced the gas oil ratio. More clearly, Case-Bp-10-10 had been ran and the matching obtained for the oil rates only and not for the gas rates. After reducing the bubble point pressure from 10 to 4 bars, Case-Bp-04-04 had been ran and the matched case obtained for the oil and gas rates. The results shows that the Case-Bp-04-04 is acting better than the Case-Bp-10-10 regarding the wellhead and bottom hole pressure.

After validating the model, four prediction scenarios have been ran. The main aim here was to produce for longer period without any artificial lift and to increase the recovery. As it is obvious, the excessive production rate in highly fracture carbonate reservoirs with low matrix porosity and low matrix permeability lead to faster drop of the reservoir pressure and finally decreasing the ultimate recovery. In the first two prediction cases (one case without the three suggested wells and the other case with the three suggested wells) the oil rate production target has been set to 300 cubic meters per day for each well and the results showing the ability of production till the end of the desired prediction period generally and for the well TT-09 specially and the three suggested wells showed improvement in the recovery. The production behavior in the figures of the wells

TT-05, TT-06, TT-07, TT-08 and TT-09 is due to their existence in one group during the simulation. For example, when one well is failed to perform under the required conditions in a group it will shut down and the other wells trying to increase the production rate to fulfill the required perdition conditions. The same phenomenon can be noticed in the wells TT-A, TT-B and TT-C due to their arrangement in one group. The second two prediction cases (one case without the three suggested wells and the other case with the three suggested wells) have another production condition which the target rate for each well is set to 500 cubic meters per day. Here the prediction scenario can not reach the desired end of the prediction period generally due to the excessive production rate in comparison with the first two prediction cases and the three suggested well assisted in increasing the recovery in a certain time but ultimately showed no effect on the recovery and that is why a fifth prediction scenario has been carried out but this time by converting the three producers to gas injectors and it showed improvement in oil recovery.

Three well locations have been suggested and included in the mentioned prediction cases. This group of wells is starting the production from first of January 2014. The results is demonstrating that the well TT-B in both prediction scenario (in which the three suggested wells have been involved as producers) performing better than TT-A and TT-C and TT-A is better than TT-C. There are a lot of possible new well locations that can be set and the location selection for the wells TT-A, TT-B and TT-C was due to further investigation for those locations.

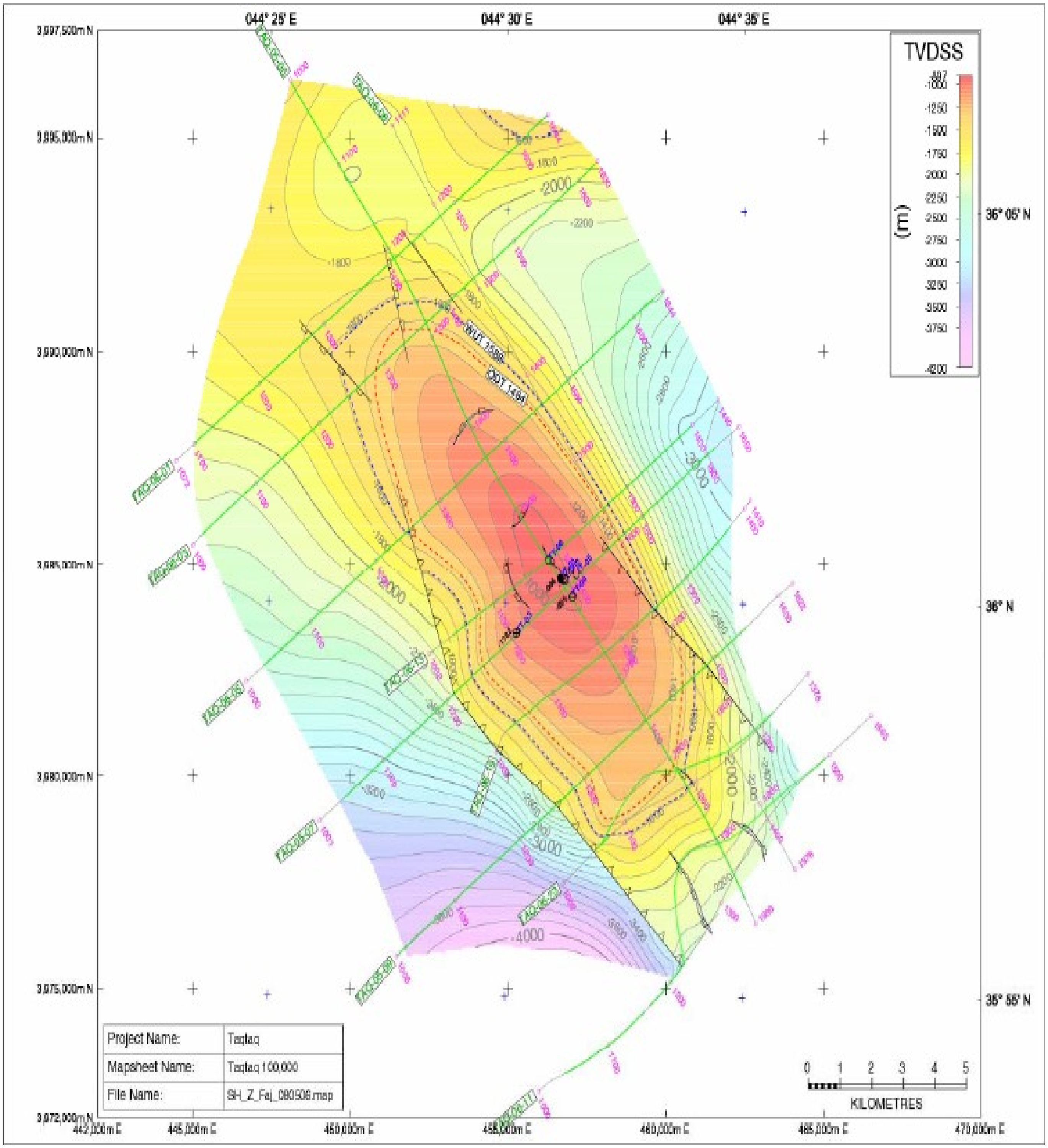
To sum up, such investigations are very important for oil field development and management especially for the new oil fields like Taq Taq oil field to avoid rapid reservoir depletion and increase the ultimate recovery. A three dimensional geological mode has been built for Taq Taq oil field and calibrated via history matching process. Two prediction scenarios have been performed and the results shows that the one with less excessive production rate can produce for longer period than the one with more excessive production rate. Three wells have been suggested and included in the prediction scenarios. Fifth prediction scenario has been carried out in which the three suggested wells used as gas injectors and the result showed their effect in increasing the recovery. TT-B is acting better than TT-A and TT-C as producers. Regarding the water production rate and water cut, it was almost nothing produced and that is why nothing mentioned about it.

5.2 Recommendations

1. The importance of the simulation is reducing costs in reality. Here more well locations can be tried and included in the simulation till finding the optimum location and then coming to suggest which one can be drilled in reality to develop the field and improve the recovery.
2. Petrel and Eclipse allowed further investigations by converting some producers to injectors. Here the effect of the water injection can be tried and gaining knowledge about its contribution to the reservoir performance in term maintaining the reservoir pressure.
3. Playing with the chock sizes is another possible way to manage the reservoir in which the water cut can be controlled in future.
4. In later stages of the life of the field, artificial lift can be used. Submersible pumps can be set or gas lift can be used.
5. In longer term, enhanced oil recovery methods can be investigated. After determining the screening criteria, the optimum enhanced oil recovery can be chosen.

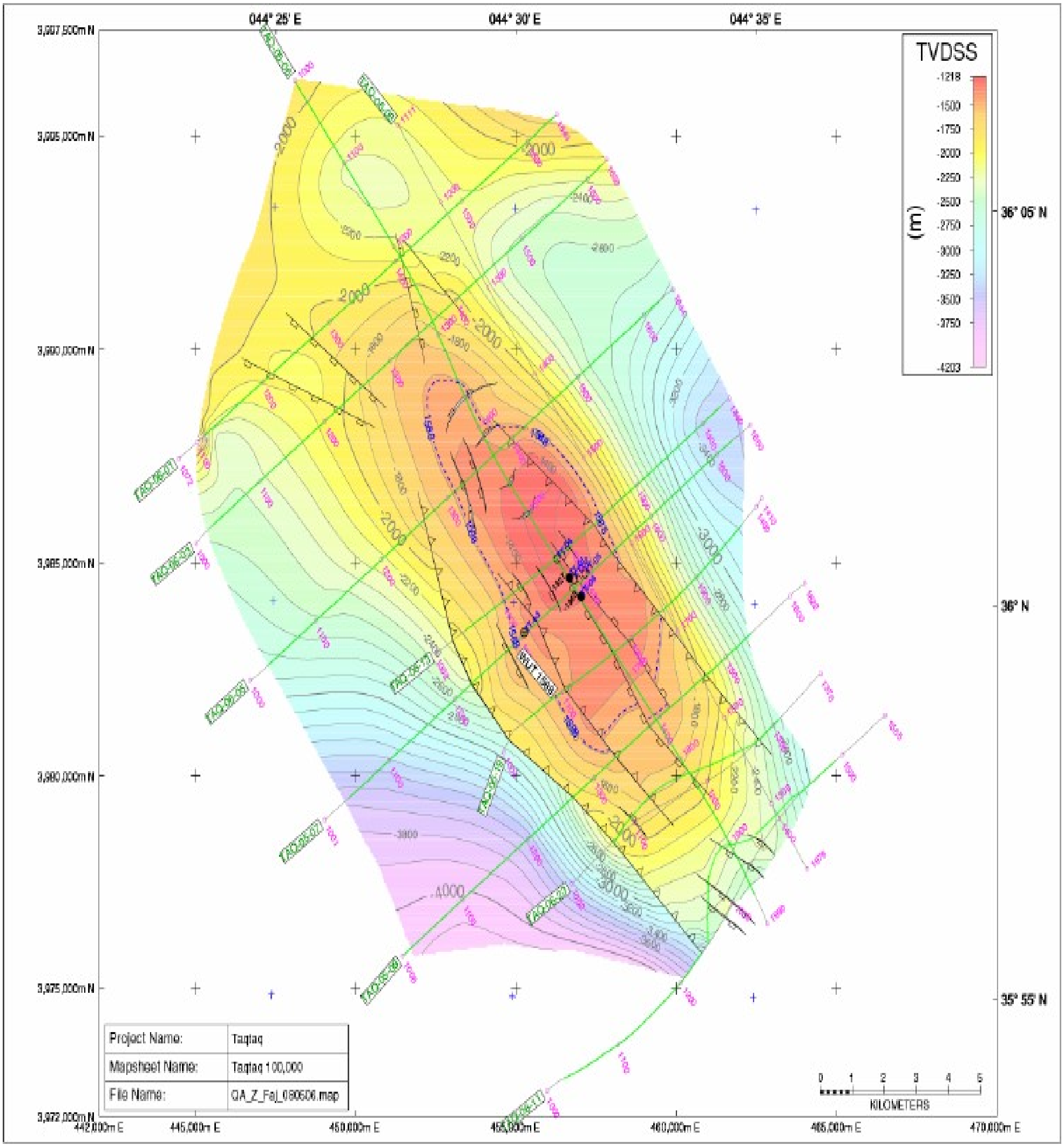
Appendix A1

Top Shiranish formation contour map



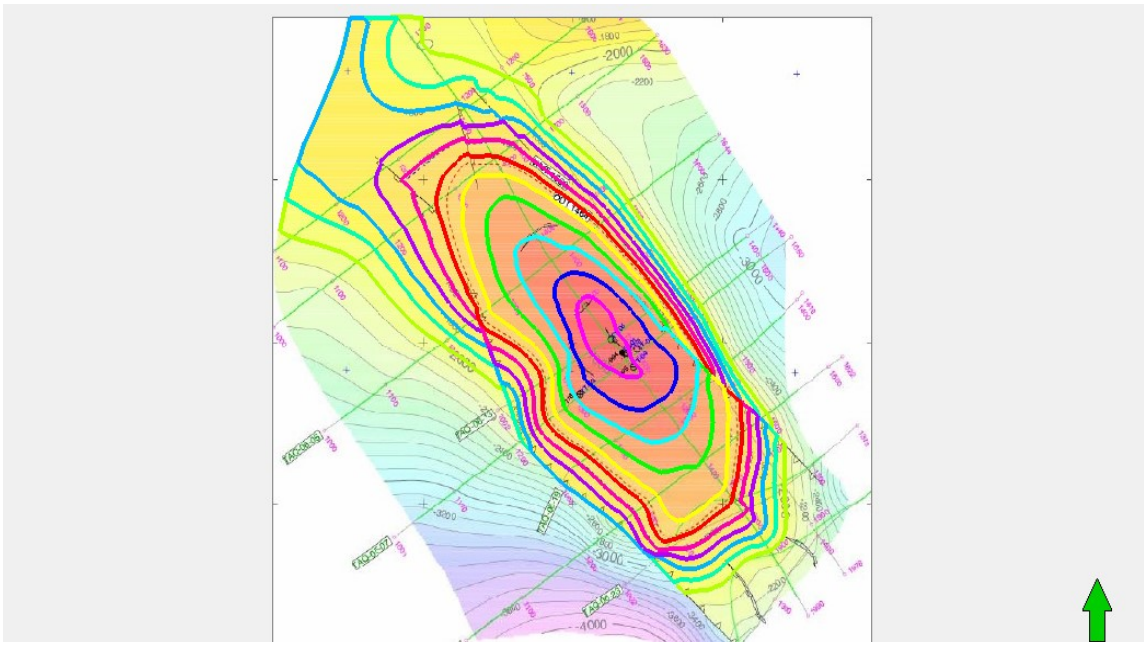
Appendix A2

Bottom Kometan formation contour map



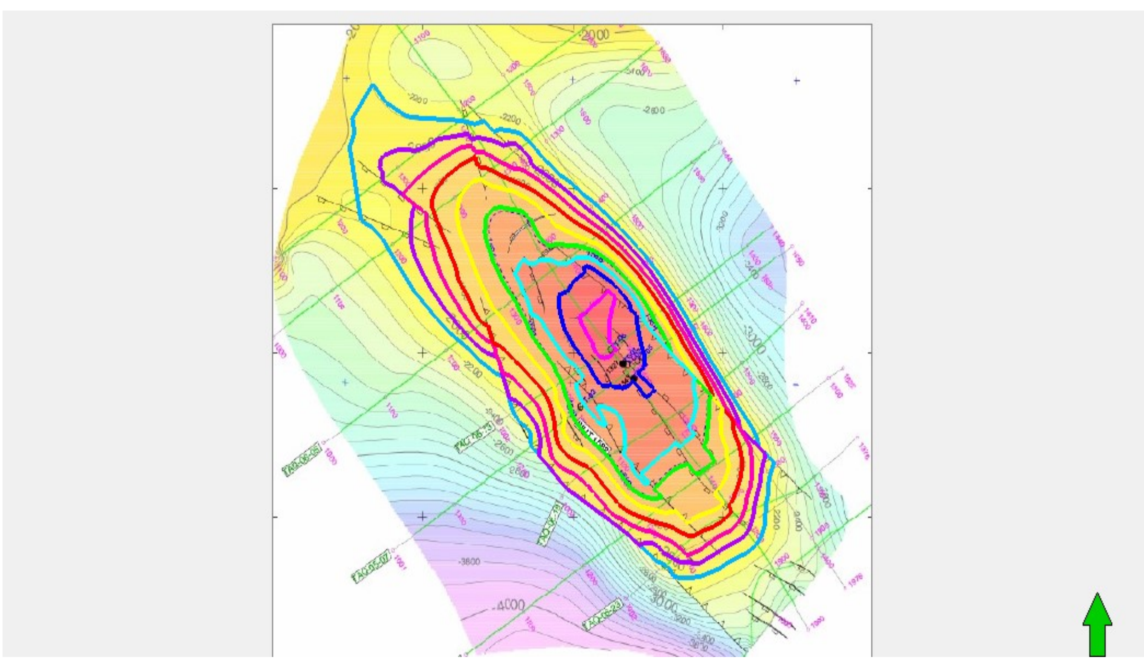
Appendix A3

Top Shiranish formation polygons



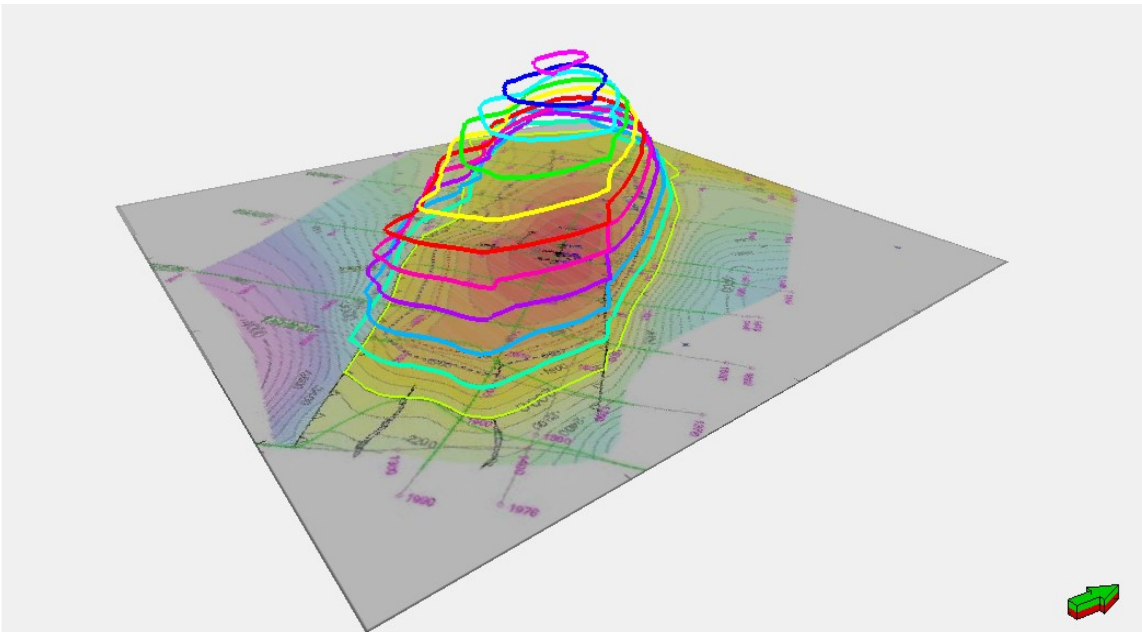
Appendix A4

Bottom Kometan formation polygons



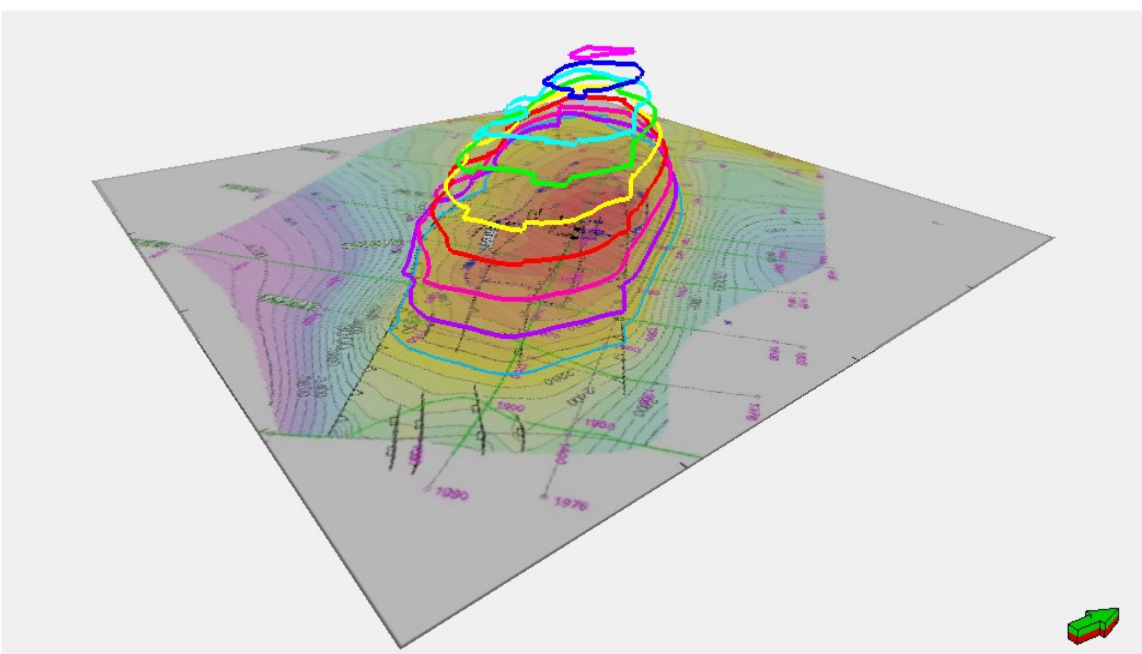
Appendix A5

Top Shiranish formation 3D polygons



Appendix A6

Bottom Kometan formation 3D polygons



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